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Eric S. Peterson
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Idaho National Engineering and Environmental Laboratory
Bechtel BWXT Idaho, LLC

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Eric S. Peterson
Idaho National Engineering and Environmental Laboratory
P.O. Box 1625
Idaho Falls, ID 83415-2208

Jessica Trudeau, Bill Cleary, and Michael Hackett
Metaldyne, Inc.
8001 Bavaria Road
Twinsburg, OH 44087

William A. Greene
SpinTek Filtration, LLC
10851 Portal Drive
Los Alamitos, CA 90720

April 2003

Idaho National Engineering and Environmental Laboratory
Chemistry Department
Idaho Falls, Idaho 83415

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ABSTRACT

An active-surface membrane technology was used to separate a die lube manufacturing wastewater stream consisting of various oils, hydrocarbons, heavy metals, and silicones. The ultrafiltration membranes reduced organics from initial oil and grease contents by 20–25X, carbon oxygen demand (COD) by 1.5 to 2X, and total organic carbon (TOC) by 0.6, while the biological oxygen demand (BOD) remained constant. The active-surface membranes were not fouled as badly as non-active-surface systems and the active-surface membrane flux levels were consistently higher and more stable than those of the non-active-surface membranes tested. Field testing demonstrated that the rotary microfilter can concentrate the die lube, i.e. remove the glycerin component, and produce a die lube suitable for recycling. The recycling system operated for six weeks with only seven cleaning cycles and no mechanical or electrical failures. Test data and quality records indicate that the die casting scrap was reduced from 8.4 to 7.8%. There is no doubt that this test yielded tremendous results. This separation process presents significant opportunities that can be evaluated further.

SUMMARY

Metaldyne, Inc. generates a complex die lube wastewater stream in its manufacturing operation that cannot be directly discharged to the environment. The wastewater contains oils, hydrocarbons, heavy metals, and silicones. A team from Metaldyne, SpinTek, LLC, and the Idaho National Engineering and Environmental Laboratory tested an active-surface membrane technology for separating this waste stream; the ultimate goal is to recycle the major components, concentrate the contaminants for disposal, and dispose of the clean water permeates from the membranes into a municipal sewer.

Our laboratory and field studies show that Metaldyne's wastewater can be cleaned up using active-surface membrane technology. Active-surface ultrafiltration membranes reduced organics from initial oil and grease contents by 20–25X, carbon oxygen demand (COD) by 1.5–2X, and total organic carbon (TOC) by 0.6, while the biological organic carbon demand (BOD) remained constant. The metals content of the solutions can be reduced significantly using tight ultrafiltration active-surface membranes. The active-surface membranes were not fouled as badly as non-active-surface systems. The active-surface membrane flux levels are consistently higher and more stable than those of the non-active-surface membranes tested.

The field tests of the ST-II rotary filter system were very promising. The die lube concentration tests achieved the goal of 20X and the filtrate was clear and colorless, indicating nearly complete removal of the die lube. One test further concentrated the feed to 50X, but the membrane water flux decreased so much as the concentration went from 20X to 50X that this proved to be too low for commercial use.

The field results for glycerin removal and die lube recycling were also very favorable. The rotary microfilter concentrated the die lube components from the waste stream, and then the contaminating glycerin was washed out with water, producing a die lube suitable for recycling. The recycling system operated for six weeks with only seven cleaning cycles and no down time due to mechanical or electrical failure. There is no doubt that this full-scale production test yielded tremendous results—it proved that recycling of die lubricant is possible and reduced die casting scrap from 8.4 to 7.8%. Further evaluation is needed to determine if it is cost effective.

ACKNOWLEDGMENTS

Special thanks go to the people that made this project possible. The Metaldyne team included Eddie Bingham, Bill Cleary, Robert Stuhldreher, Jessica Trudeau, and Michael Hackett; the SpinTek team included Bill Greene and Jason Gilmore; and the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy's Office of Industrial Technologies team included Harvey Wong, Ehr-Ping Wang Fu and Denise Swink.

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A Membrane Process for Recycling Die Lube from Wastewater Solutions

1. INTRODUCTION

Water treatment is a major separations challenge for all industrial water users. Environmental concerns and energy conservation have led both the industrial and governmental sectors to make significant efforts to develop energy-efficient separations processes.[1,2] The Idaho National Engineering and Environmental Laboratory's Inorganic Membrane Technology Research Program is an ongoing Department of Energy effort to develop energy-efficient membrane separation processes in collaboration with industry. Membranes are energy efficient compared to traditional phase separation processes such as distillation. However, many membrane materials degrade in the harsh thermal and chemical environments frequently encountered in industrial settings. The Idaho National Engineering and Environmental Laboratory (INEEL) membrane program has traditionally focused on polymeric membrane separations.[3-11] Recently, however, the program has begun working in the area of filtration and has teamed with Metaldyne, Inc. and SpinTek Filtration, LLC to develop a means of separating wastewater solutions generated by the die casting process. This report presents the results of that collaboration.

Metaldyne generates a complex wastewater stream that contains soaps, detergents, oils, hydrocarbons, heavy metals, and silicones. In 1999, Metaldyne's Twinsburg facility, in cooperation with The North American Die Casting Association, the Department of Energy's Office of Industrial Technology, and INEEL, launched an initiative to investigate the potential to separate solids from wastewater. The goal was to improve discharge quality, reduce loading on the plant's treatment system, and, potentially, recover these solids for reuse. Wastewater streams similar to Metaldyne's are common in the metal casting industry, and there are many other applications for a reliable, effective process for treating this type of wastewater.

Treating manufacturing wastewater requires a simple, rugged, and durable process. The system must be capable of handling a wide compositional range, and varied concentrations, of wastewater components and consistently providing purified water suitable for reuse. The system needs to remove large solids as well as very small organic molecules of detergents, other surfactants, and specific organic chemicals. In addition to purifying the wastewater, the system must be able to concentrate the feed water contaminants to a thick slurry, both for potential recycling and for minimizing the waste for storage and subsequent disposal.

To address this challenging problem, a three-phased project was defined. Each phase was independent and, at its completion, the feasibility of continuing the project was evaluated. The phases were:

- Phase 1—Problem Identification, Evaluation, and Bench-Scale Process Studies

  We identified the real bottlenecks in current separations processes, the specific families of materials that are causing fouling, and possible methods for eliminating the fouling problems. We established the scope of the bench-scale experimental studies. These studies examined membrane fouling by the feed streams, fouling prevention methods, membrane replacement costs, and lifetime evaluations.

- Phase 2—Recommendations for Alternative Processes Studies

  The Phase 2 recommendations were based upon the studies performed in Phase 1 and the suggested field studies for Phase 3. After performing Phase 1, we decided that Phase 2 would focus on demonstrating the capability to concentrate die lube by separating it from Metaldyne's wastewater.

- Phase 3—Initiation of Field Studies Based upon the Results of Phases 1 and 2

  One technology was to be selected for field studies and the separations of concern were to be fully evaluated at the mini- or full pilot-scale. Based on the results from Phases 1 and 2, we determined that Phase 3 would be to concentrate the die lube as in Phase 2, then wash the glycerin component from the concentrated die lube/glycerin mixture and reuse the die lube in casting operations on a single full-scale, full-production die casting machine.

  The following sections describe our research and results.

2. TECHNICAL APPROACH

During Phase 1, we identified three commercial technical approaches to separating complex wastewater streams such as Metaldyne's. These separation systems all use an active porous membrane surface as the primary contactor with the medium to be filtered. The companies selling these systems are MonTec Associates of Butte, Montana; New Logic, Inc. of Emeryville, California (now owned by Pall Corporation); and SpinTek Filtration Systems, Inc., from Huntington Beach, California. Other competitive technologies may exist; however, they were not identified during the careful literature and Internet research in Phase 1.

SpinTek was selected as the partner for this research for several reasons, including the ruggedness of their design, the novelty of their technology, their history of installed commercial systems, and the overall cost. However, during Phase 1 we continued to search for, and evaluate, other potential partners that might be able to contribute to these studies. No other potential partners were identified, resulting in selection of SpinTek as the partner for Phases 2 and 3. Thus, the active-surface membranes manufactured by SpinTek were finally chosen as the systems of choice for this application. As a consequence of selecting SpinTek as a partner, the goal of this project became demonstrating their microfiltration rotary membrane technology for die casting wastewater applications.

SpinTek's ST-II/Speedy™ rotary membrane system has one to twenty-five spinning membrane disks with 1.0 ft^2 of membrane per disk (Figures 1 and 2). These units may be placed in series or parallel, as needed, to obtain the desired membrane surface area. The membrane disk consists of a central Ryton™ core that is overlaid with a permeate carrier mesh. The disc-carrier system is then overlaid with a selective filtration membrane and the entire assembly glued with appropriate adhesives. The rotation rate on the discs we used was fixed at 1200 rpm. The ST-II/Speedy™ can be fully automated, including feed flow, pressure, temperature instrumentation, permeate flow rate, and all the necessary safety instrumentation. The systems we used have automated data logging of the above instrumentation.

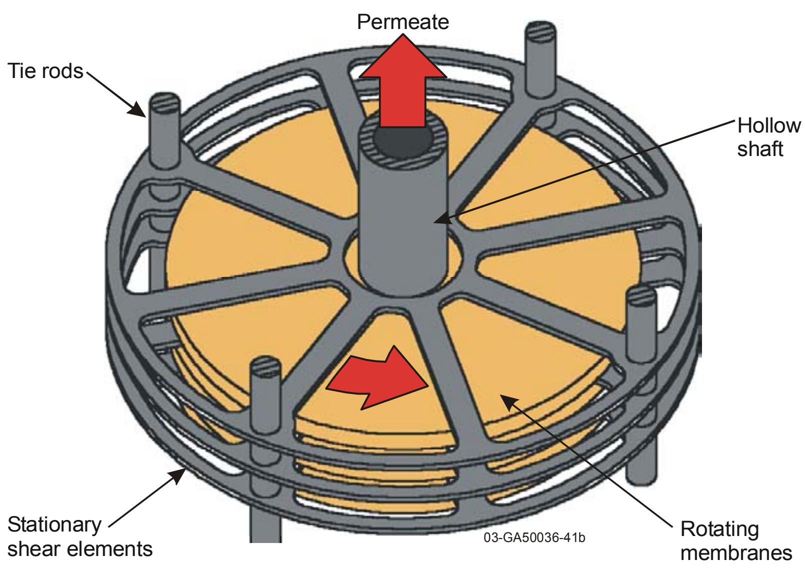


Figure 1. Typical rotary membrane disc assembly, shown with three discs and stationary "wagon wheel"elements.

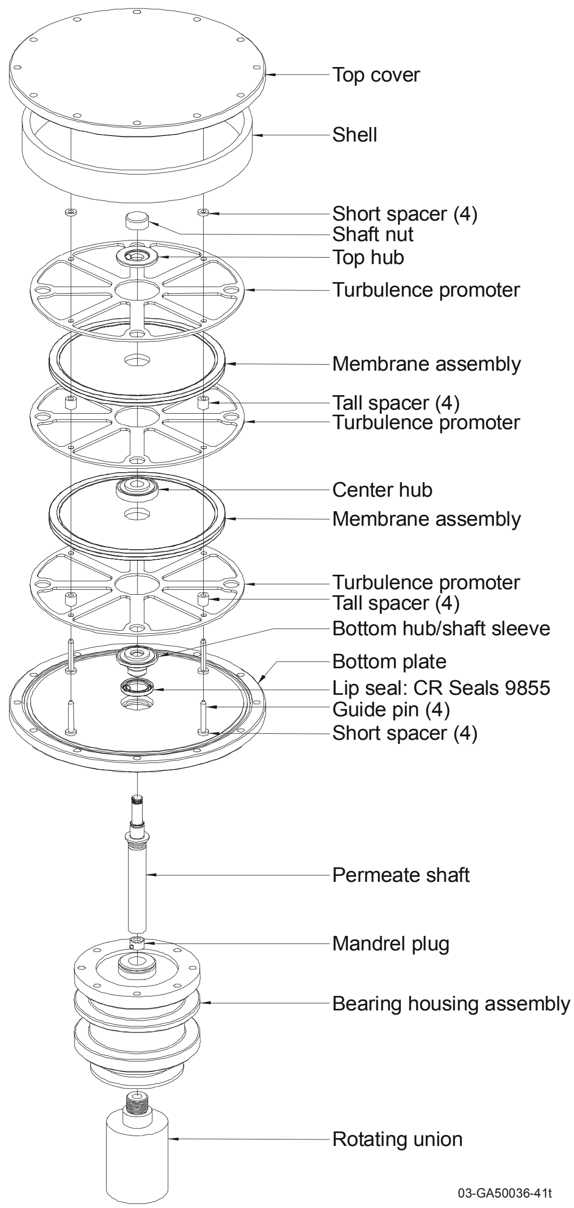


Figure 2. Exploded view of the rotary membrane system.

We planned to use SpinTek's ST-II rotary microfiltration system (Figure 3) with 0.1 micron ceramic-stainless steel or polymeric composite membranes to remove all of the suspended solids and many of the organic contaminants. If necessary, the filtrate from the ST-II could be polished by a nanofiltration system to remove smaller organic chemicals from the wastewater. This approach, shown schematically in Figure 4, was followed. In Phase 1, samples of the wastewater solution were tested in the laboratory on a small, flat-sheet test system and a single disk rotary filter. In Phase 2, two five-disk ST-II/Speedy™ rotary microfilters were used to demonstrate that the system could concentrate die lube by separating it from wastewater. In Phase 3, the two five-disk ST-II rotary microfilters were used to separate die lube for recycling. First, the die lube, combined with wastewater, was dewatered. Then the retentate/die lube was flushed of glycerin using the ST-II rotary membrane filter to separate the die lube from the water/glycerin mixture. Finally, the die lube was reused on a single full-scale die casting machine at full production.

Figure 3. ST-II Speedy™ system.

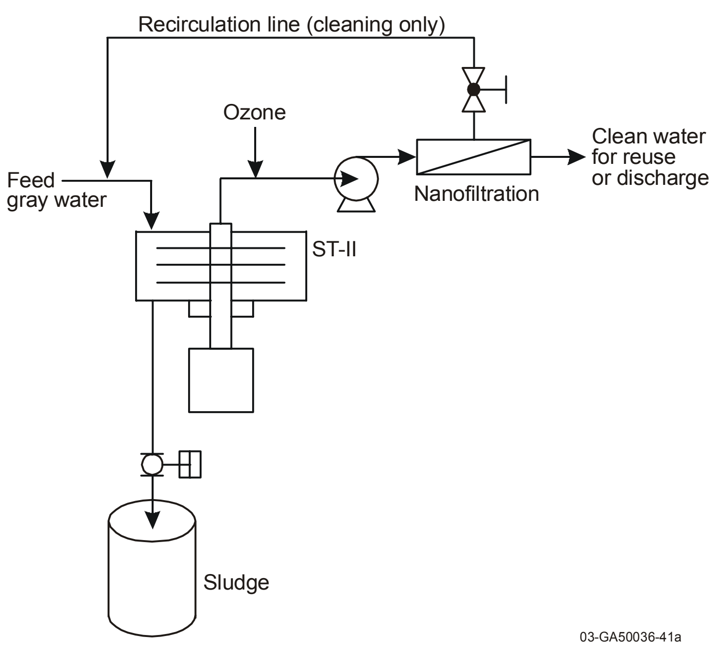


Figure 4. ST-II filtration system process flow.

3. PHASE 1: LABORATORY MEMBRANE EVALUATION

3.1 Experimental Procedure

SpinTek assembled two test platforms consisting of a membrane filtration system and a pumped skid. The static test cell (STC), shown in Figure 5, contained one flat-sheet membrane test sample, while the ST-IIL had a single disk rotary with the membrane filter. The major difference between the two systems is the shear generated at the surface of the membrane. The STC has a static membrane, while the ST-IIL uses a membrane disk rotating at high velocities to generate shear (the membrane rotates at 1200 rpm, with an average radial Reynolds Number, $Re_{r(avg)}$, of 2.0×10^5 to 1.2×10^6).[12] The membranes used in these bench-scale systems are also used in the full-scale ST-II rotary membrane system.

Membranes were tested in the bench-scale systems with wastewater provided by Metaldyne. The static system allowed initial membrane screening while the single disc spinning membrane system offered initial data on specific membranes that passed the initial static testing. This was a rapid method of membrane selection for this application.

The general layout of the bench-scale STC testing equipment is shown in Figure 6. The process solutions were pumped from the feed tank to the STC membrane system. A throttling valve on the feed pump controlled the flow to the system. A back-pressure control valve maintained a constant pressure on the membrane system. The feed solution, supplied by Metaldyne, was pumped from 55-gallon drums into a 2-liter feed tank equipped with an agitating stirrer. The stirrer assured good mixing of the feed solution prior to its circulation in the membrane testing system. The feed tank was held at constant temperature. During testing, data were recorded every 15 min, or as needed. Membrane fluxes are defined as:

$$\text{Flux} = \frac{\text{Filtrate Flow Rate}}{\text{Area of Membrane}}, \text{ which is measured in units of } \frac{\text{gallons per day}}{\text{square feet}} \text{ or gfd.}$$

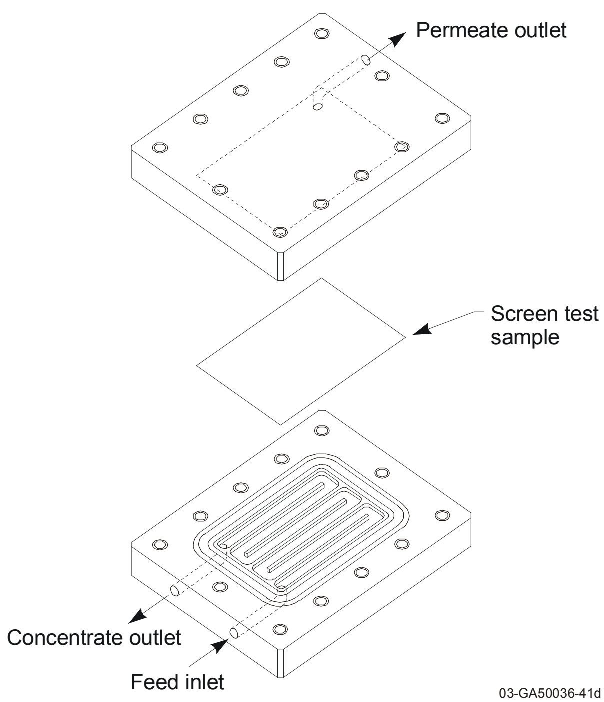


Figure 5. Static test cell.

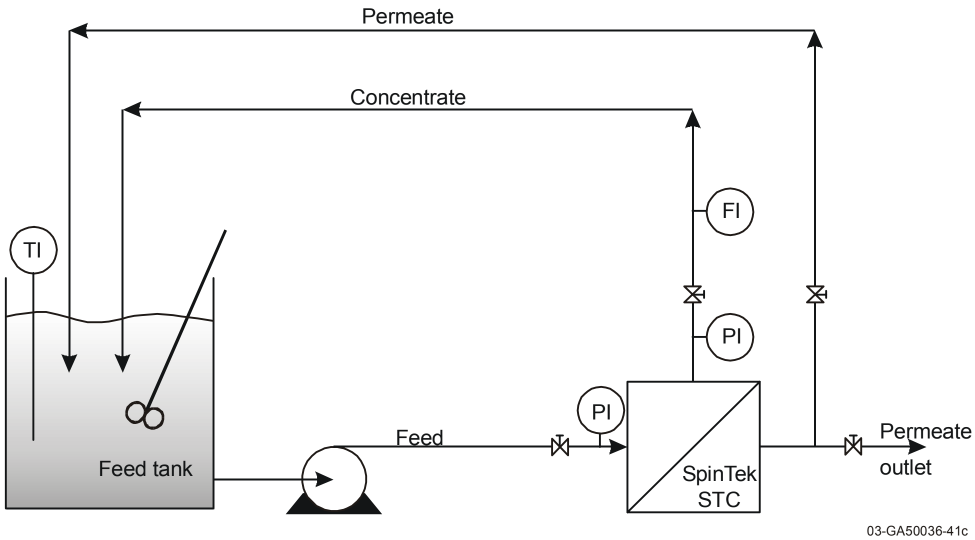


Figure 6. Process flow and instrument diagram for the static test cell.

A nanofiltration polishing step was also evaluated to remove the remaining metal ions from the solution. The assumption was that, under the conditions at Metaldyne's plant (temperature, pH, etc.), the metal ions would be clustered and contained within the larger organic phase globules, as is typically observed with solvent extraction systems. Therefore, one could assume that a nanofilter would remove the metal ions from the stream.

3.2 Results

3.2.1 Static Test Cell Tests

Unexpected fouling and flux decline problems encountered using the ceramic-stainless steel composite membranes, Figures 7 and 8, suggested that we not pursue these membranes any further. The results of our experiments with the polymeric membranes, shown in Figure 9, suggested that we pursue these membranes and their relatives for the Metaldyne water treatment process. Thus, the polymeric membranes were slated for further evaluation on the ST-IIL rotary membrane. (Later in the study we did pursue the stainless-steel ceramic composite membranes due to the low durability of the polymeric membranes in Metaldyne's particular feed stream, a problem that only became evident in the early stages of our pilot studies. Data from the STC tests are included in the appendix.)

3.2.2 ST-IIL Rotary Membrane Tests

Two different polyvinylidene fluoride-based membranes were tested, an ultrafiltration membrane with a 100,000 molecular weight cut-off (0.05 micron, 400 angstrom mean pore diameter), and a "tighter" ultra/nanofiltration membrane with a 10,000 molecular weight cut-off (0.005 microns, 40 angstrom mean pore diameter). These membranes were made by different manufacturers, and the pore sizes probably are not exactly what they are specified in relationship to one another, which likely explains why they had similar fluxes even though their pore sizes differed by a factor of ten. Flux and concentration profiles from these tests are shown in Figures 10 through 13. At the completion of each of these experiments, the permeate solutions were allowed to stand overnight before being delivered to the analytical labs. During this time, significant hydro-gel-like precipitates formed in the permeate solutions. The gels, speculatively, are hydrated aluminum, zinc, and iron oxy-/hydroxy-species.[13] The gels are very pH sensitive, and

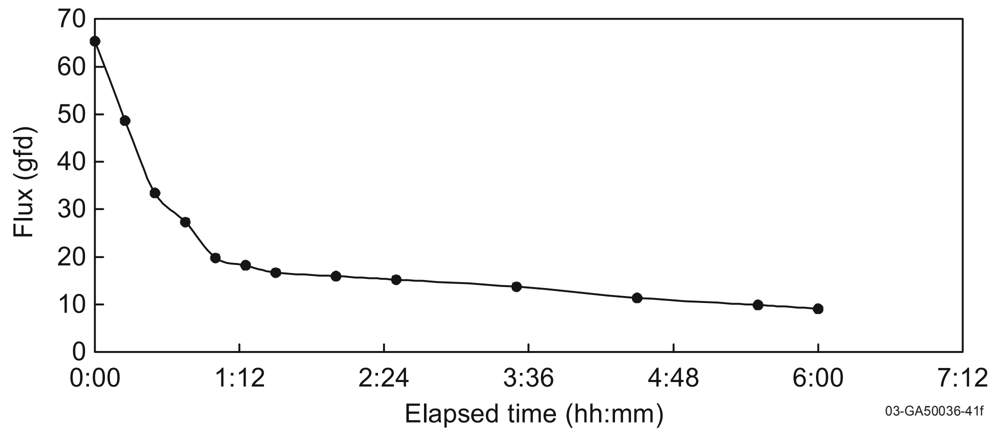


Figure 7. Flux profile for STC with 0.15 micron ceramic membrane. The test was stopped due to low flux.

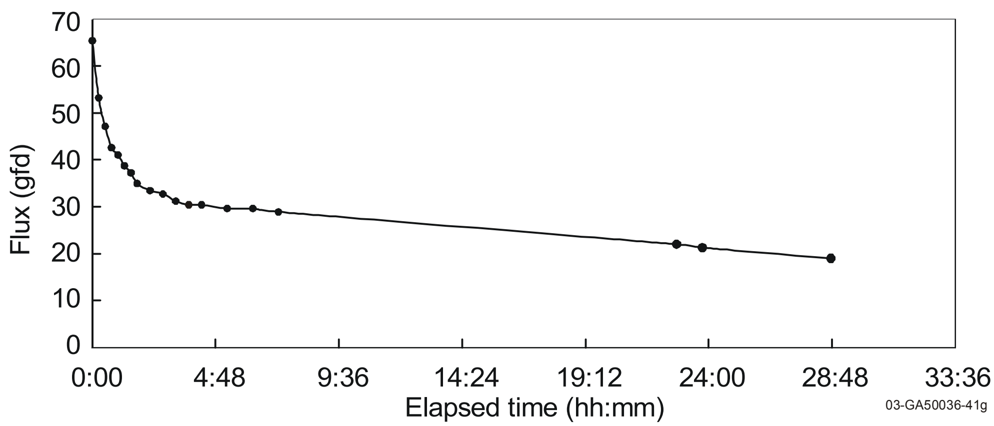


Figure 8. Flux profile for STC with 0.007 micron ceramic membrane.

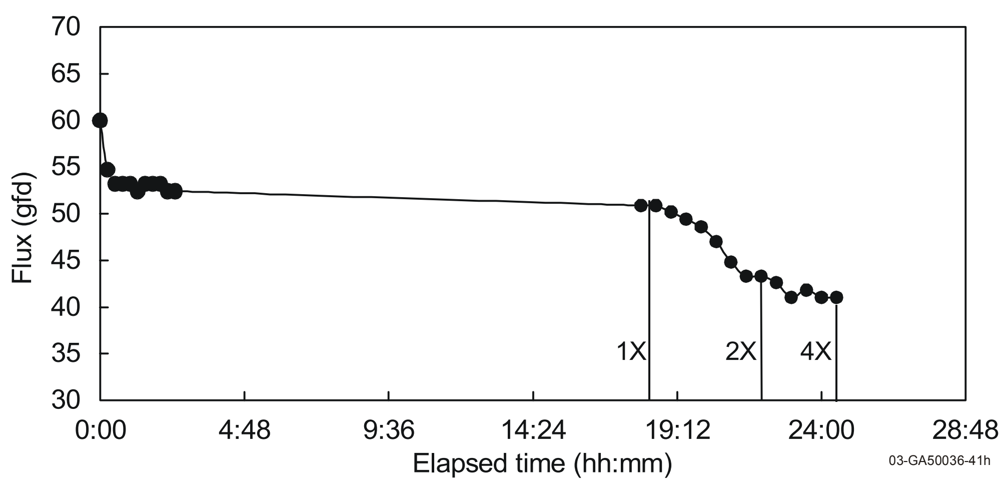


Figure 9. Flux profile for STC with 100,000 molecular weight cut-off (0.05 microns) polymeric membrane.

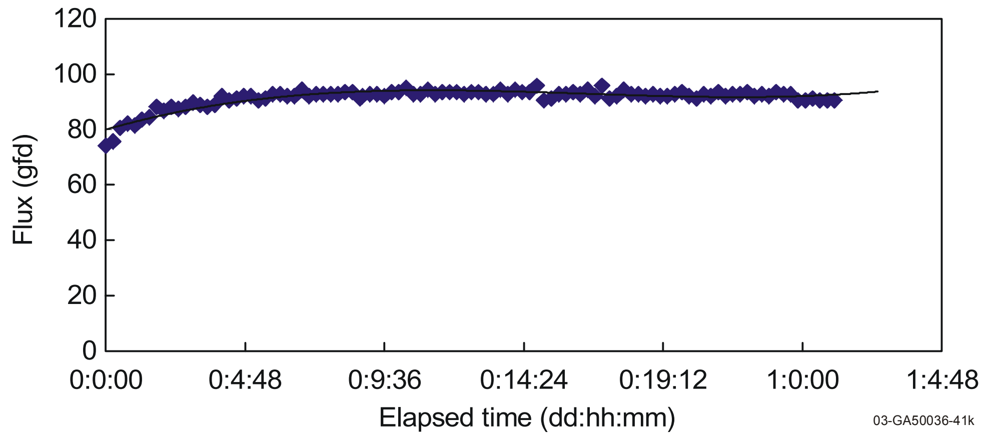


Figure 10. Flux profile for 100,000 NMWC cut-off polymeric membrane (ST-II-1 Test 2).

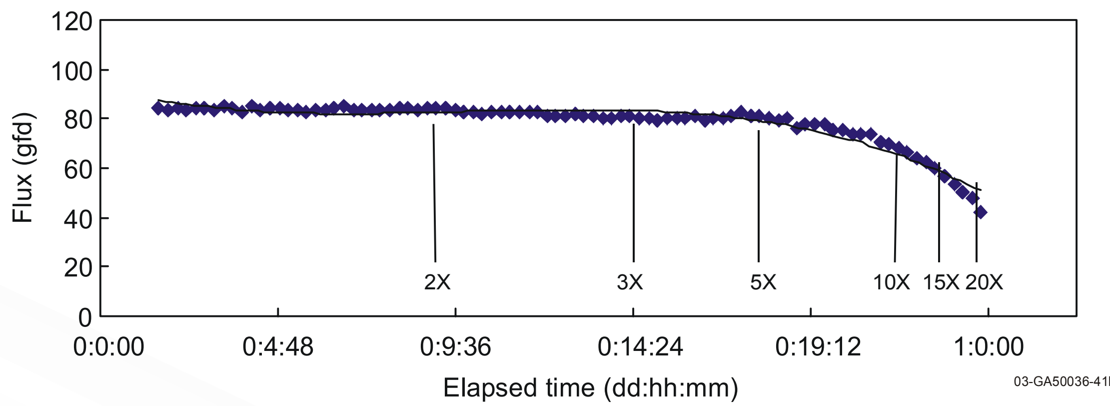


Figure 11. Concentration profile for 100,000 NMWC cut-off polymeric membrane (ST-II-1 Test 2).

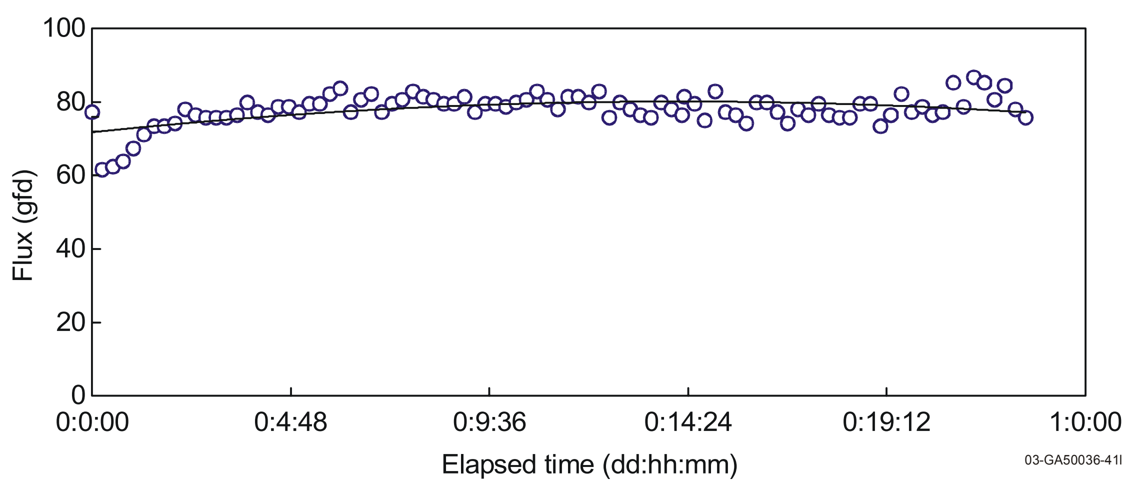


Figure 12. Flux profile for 10,000 NMWC cut-off polymeric membrane (ST-II-1 Tests).

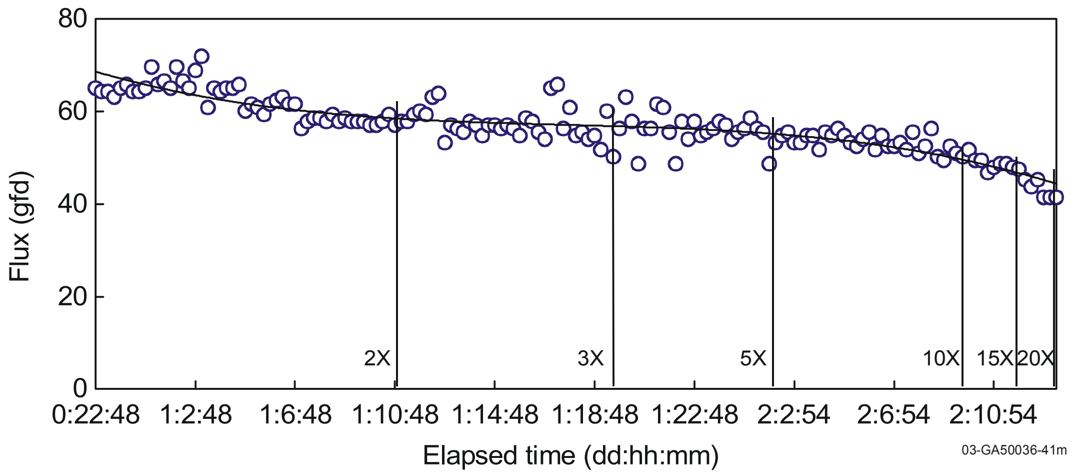


Figure 13. Concentration profile for 10,000 NMWC cut-off polymeric membrane (ST-II-1 Test 3).

dissolve immediately with drop-wise additions of acid in 1-L samples. Due to the complex nature of the solutions that have been evaluated (i.e. high aluminum and zinc contents), the chemical analyses required greater time to accomplish than originally anticipated. Prior to analysis, all samples were acidified with drop-wise additions of hydrochloric acid to assure that all metal ions were dissolved in the solutions.

Truesdail Laboratories, Inc., Tustin, CA, a commercial laboratory certified by the U.S. Environmental Protection Agency (EPA), performed the chemical analyses. The data are summarized in Table 1; the concentration factors for each component are summarized in Table 2. The large number and volume of samples taken at high concentrations for laboratory analysis after tests with the ultrafiltration membrane resulted in the remaining raw feed having slightly lowered concentrations for the ultra/nanofiltration membrane tests. This resulted in reduced metals and organics in the concentrates, but should have had no effect on the overall permeate analysis because the concentrations were not significantly different.

3.2.3 Static Nanofiltration Membrane Tests

The results, presented in Figures 14 and 15, show, to our surprise, that a nanofilter is not adequate to remove the metal ions from the stream. Therefore, a membrane cleaning procedure was developed in Phase 2. Truesdail Laboratories also performed chemical analyses on the samples resulting from these tests; the data are summarized in Table 3.

3.2.4 Conclusions from Bench-Scale Tests

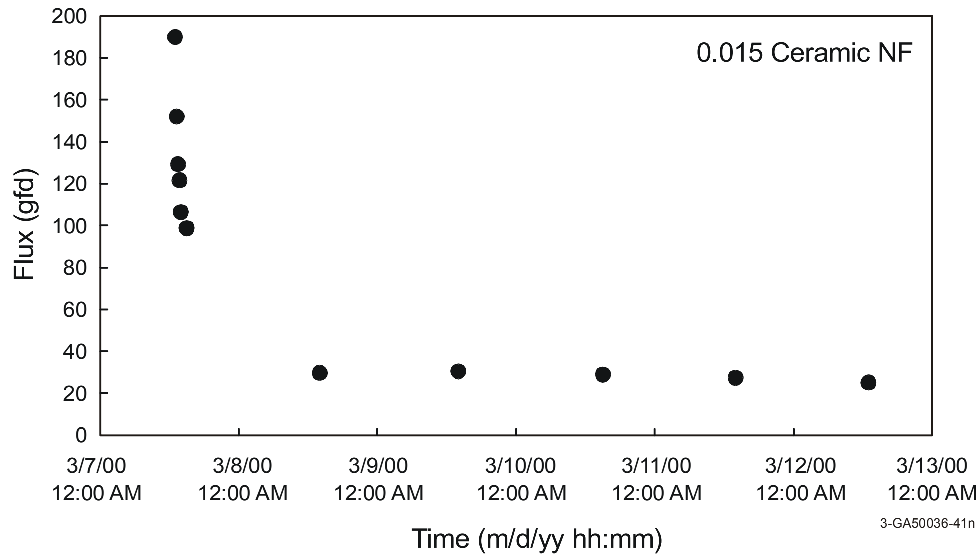
Based upon our experimental results, we asserted that the active-surface ultrafiltration membranes can substantially reduce organics found in the die-casting solutions. The initial oil and grease are reduced by 20–25X, carbon oxygen demand (COD) by 1.5–2X, total organic carbon (TOC) by 0.6, while biological oxygen demand (BOD) remained the same. As the organic concentrations of die lube increased in the retentate, the permeate concentrations of the organics remained remarkably similar to their original concentrations. This speaks for an equilibrium being reached and the membrane pore size being very stable.

Table 1. Chemical analyses for laboratory tests with polymeric membranes.

Sample ID	TOC mg/L	BOD mg/L	COD mg/L	Oil & Grease mg/L	Pb mg/L	Cu mg/L	Ni mg/L	Zn mg/L
100,000 MW cut-off polymeric membrane								
1) Initial Perm.	2108	2262	6296	11.2	ND	ND	0.08	0.47
2) Raw Feed	3463	2714	12567	225	ND	0.12	0.08	0.55
3) 1X Final	2143	2456	6174	12.7	ND	ND	ND	0.46
4) 4X Conc.	9287	6030	48230	490	ND	0.70	0.10	0.74
5) 4X Perm.	2272	2445	6456	12.0	ND	ND	0.09	0.47
6) 8X Conc.	19637	8072	87928	634	0.36	1.44	0.15	1.00
7) 8x Perm.	2683	2277	6915	10.5	ND	ND	0.09	0.52
8) 12 X Conc.	22518	3438	117498	1078	0.51	2.01	0.19	1.22
9) 12 x Perm.	2488	2295	7344	11.6	ND	ND	0.11	0.51
10) 16X Conc.	29404	11789	163077	1538	0.70	2.80	0.22	1.38
11) 16X Perm.	2839	1558	8593	6.5	ND	ND	0.10	0.54
12) 20X Conc.	43339	12250	206172		1.04	4.00	0.29	1.72
13) 20X Perm.	2680	4014	8725	12.4	ND	ND	0.09	0.51
10,000 MW cut-off polymeric membrane								
14) Initial Perm.	2406	2219	7393	11.3	ND	ND	0.08	0.52
15) Raw Feed	3210	2416	11590	274	ND	0.11	0.10	0.54
16) Final Perm.	2211	1443	6758	13.8	ND	ND	0.08	0.51
17) 4X Perm.	2206	2049	7115	5.6	ND	ND	0.08	0.51
18) 4X Conc.	6504	3388	26060	294	ND	0.36	0.09	0.63
19) 8X Perm.	2388	2152	7012	18.4	ND	ND	0.09	0.55
20) 8x Conc.	10380	3880	47890	634	ND	0.72	0.13	0.83
21) 12 X Perm.	2606	2611	7408	9.4	ND	ND	0.09	0.57
22) 12 x Conc.	10572	4699	72370	713	0.33	1.12	0.16	1.04
23) 16X Perm.	2764	2205	8047	7.9	ND	ND	0.09	0.56
24) 16X Conc.	14340	5176	79200	944	0.35	1.31	0.15	1.01
25) 20X Perm.	2756	1979	8315	11.7	ND	ND	0.09	0.58
26) 20X Conc.	18614	6117	104687	1202	0.40	1.68	0.17	1.11

Table 2. Concentration factors for polymeric membranes in laboratory tests.

Sample ID	TOC mg/L	BOD mg/L	COD mg/L	Oil & Grease mg/L	Pb mg/L	Cu mg/L	Ni mg/L	Zn mg/L
100,000 MW								
1,3/2	1X	1X	2X	18X	ND	R	1X	1X
4/5	4X	2X	7X	41X	ND	R	1X	1X
6/7	7X	3X	13X	60X	R	R	1X	1X
8/9	9X	1.5X	15X	98X	R	R	1X	1X
10/11	10X	8X	19X	220X	R	R	2X	2X
12/13	16X	3X	24X	120X	R	R	3X	3X
10,000 MW								
15/14,16	1X	1X	2X	25X	ND	R	1X	1X
18/17	3X	1X	3X	50X	ND	R	1X	1X
20/19	4X	1X	2X	34X	R	1X	1X	1X
22/21	4X	2X	9X	75X	R	R	2X	2X
24/23	5X	2X	10X	120X	R	R	2X	2X
26/25	6X	3X	13X	100X	R	R	2X	2X



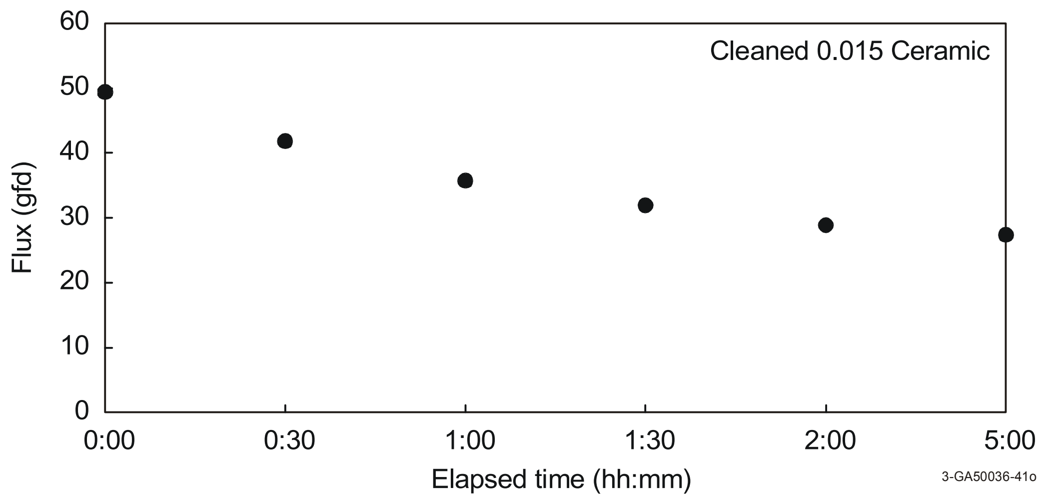
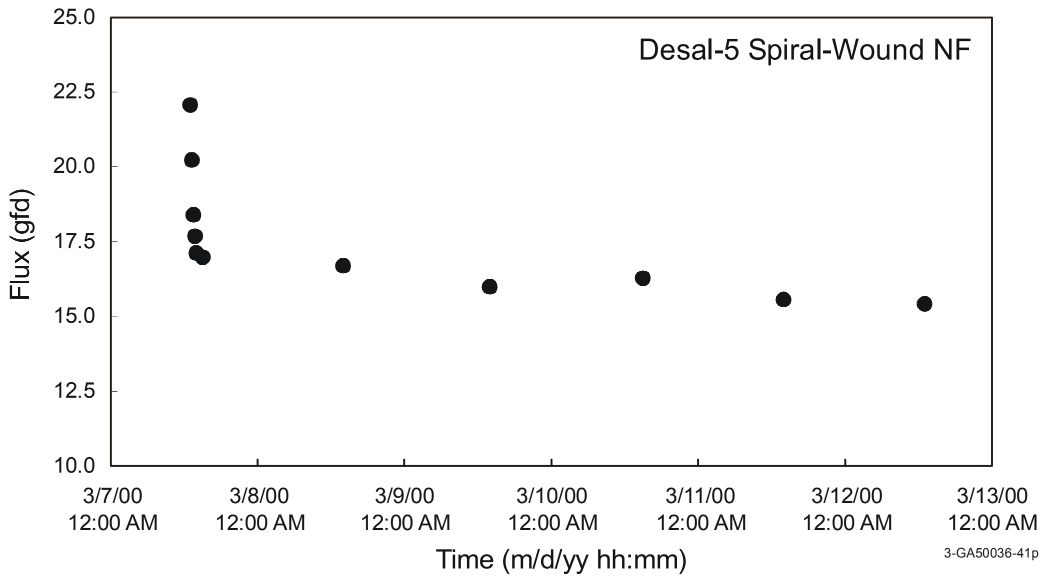


Figure 14. Performance of ceramic ST-IIL nanofiltration membrane (nominal 0.015 micron mean pore diameter) shows flux decline (top), probably due to fouling, and improvement after cleaning (bottom).



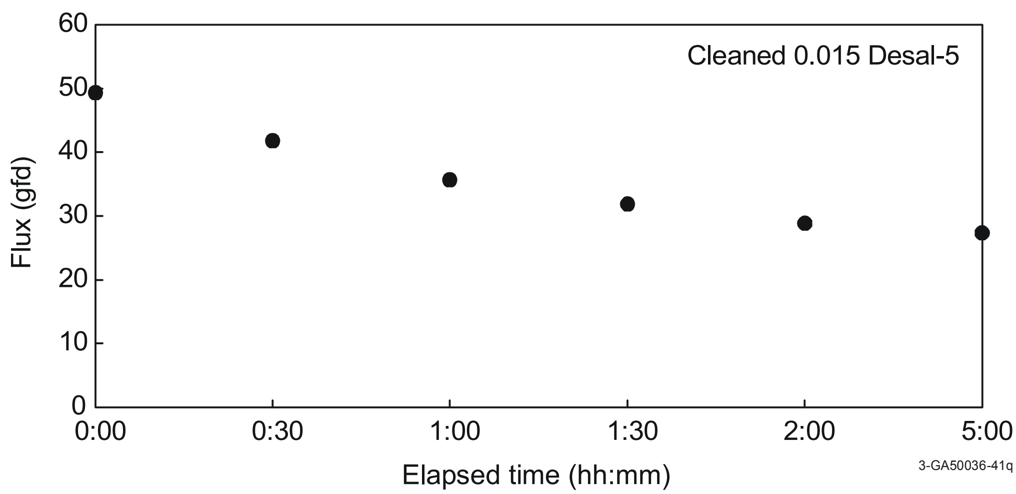


Figure 15. Performance of Desal-5 spiral-wound, static polymeric nanofiltration membrane shows flux decline (top), probably due to fouling, and improvement after cleaning (bottom).

Table 3. Chemical analyses for nanofilter tests.

Sample ID	TOC mg/L	BOD mg/L	COD mg/L	Oil & Grease mg/L	Pb mg/L	Cu mg/L	Ni mg/L	Zn mg/L
Desal-5 spiral wound cartridge								
Permeate	1510	1160	3931	ND	ND	0.09	0.24	0.63
Raw Feed	3463	2714	12567	225	ND	0.12	0.08	0.55
0.015 micron ceramic membrane								
Permeate	1894	2418	4885	ND	ND	0.05	0.23	0.42
Raw Feed	3463	2714	12567	225	ND	0.12	0.08	0.55

These studies showed that active-surface ultrafiltration membranes can reduce total metals in the aqueous phase of a die casting waste solution that is having the water removed from it. The metals concentrations in the permeate (water) are reduced significantly; however, after a period of time, several metals (notably lead and copper) are detectable in the retentate as the organic concentration of the feed solutions increases. This result suggests that the metals probably preferred to stay with the organic components of the die casting solutions. The active-surface membranes were observed to exhibit less fouling than the non-active-surface systems. The fluxes of the active-surface membranes were consistently higher and more stable than those of the non-active-surface membranes tested.

We observed that using polymer materials for the active-surface membranes provided surprisingly high fluxes and high quality separations. (However durability of the polymers became an issue for these systems when we entered the pilot phase, which led to substitution of the inorganic membranes.)

Metaldyne's previous studies with ultrafiltration followed by reverse osmosis had significant problems with membrane fouling by oils, greases, and a material that adheres to all processing equipment and membrane surfaces as well as forms a "scum," with the consistency of lipstick, on the top of the holding tanks. Metaldyne has installed a gravimetric skimmer and a prefilter for removal of particulates and oils and greases from the solutions prior to further water treatment; however, they have not successfully been able to remove all of these components. Some of the "lipstick" components are carried through the system into the membrane systems. The SpinTek active-surface membrane systems showed no significant build up of the "lipstick" as had been previously observed by Metaldyne in their reverse osmosis and ultrafiltration systems (Zenon Environmental). A cleaning procedure for the ultrafiltration membranes using detergents was developed in these experiments, and implemented. The process worked well and is described later in this report.

The preliminary studies with static nanofiltration membranes/modules as a polishing step provided very slight concentration of metal ions. A true reverse osmosis membrane, such as those already installed at Metaldyne's plant, would be most appropriate for a polishing step should it be needed. The operational cost analysis for a rotary membrane system in Metaldyne's application is summarized in Table 4.

Table 4. Rotating membrane cost analysis.

Costs			
Capital			
Rotating Membrane System	$750,000		
Commissioning	$20,000		
Shipping/Handling	$4,000		
		Total capital cost	**$774,000**
Operating			
Power cost	$0.06/KW-hr		
Cost per cleaning	$25.00		
Membrane replacement	$96,000		
Cost per Kgal			
Membrane replacement	$13.00		
Membrane cleaning	$0.26		
Power	$9.05		
Misc. operating cost	$0.56		
		Total operating cost per Kgal	**$22.87**
		Total daily operating cost	**$457.40**

Assumptions

System		Operation	
Feed water volume	20,000 gpd	Operating days/month	30 days
System output	19,000 gpd	Operating pressure	40 psig
Percentage recovery	95%	Recycle flow/disc pack	1 gal
Membrane		Total recycle flow	320 gpm
Type	0.1 micron	Recycle pressure drop	30 psig
Performance	60 gfd	Pump efficiency	80%
Diameter	11 in./disc pack	Motor efficiency	94%
Surface area	1 sq. ft/disc pack	Brake HP – Recycle pump	5.0 BHP
Disc packs/system	320	Brake HP – Rotors	200 BHP
		Brake HP – Total required	160.0 BHP
		Total system power consumption	119.4 KW-hr
		Membrane	
		Cleaning interval	5 days
		Lifetime (conservatively)	1 yr

3.3 Summary of Phase 1 Testing

Laboratory testing, using small, flat, sheet membranes and a bench-scale rotary filter, demonstrated that active-surface membrane technology was a good candidate for field testing at Metaldyne's plant. The metals content of the feed solutions was reduced significantly using tight ultrafiltration active-surface membranes. However, significant hydro-gel-like precipitates formed in the permeate solutions upon standing. The gels may be hydrated aluminum and iron oxy-/hydroxy-species.[13] These gels are very pH sensitive and dissolved immediately with drop-wise additions of acid to 1-L samples. Nanofiltration to polish the effluent concentrated the metal ions slightly. The results of the experiments were encouraging because permeates from the nanofiltration system are clear, colorless, and show only slight discoloration and no significant gel precipitation upon standing. These results provided the basis for proceeding to Phase 2 testing and evaluation.

4. PHASE 2: FIELD DEMONSTRATION OF DIE LUBE CONCENTRATION

4.1 Experimental Procedure

After the successful completion of Phase 1, SpinTek fabricated a system consisting of two five-disk ST-II rotary microfilter units (Speedy™ systems), a feed pump, storage tank, associated piping and valves, and a fully automatic control panel. The system was designed to provide continuous operation of the ST-II filter on wastewater and allow high concentrations of the feed samples. The general layout of the pilot testing process equipment is shown in Figure 16. The process solutions were pumped from the feed tank to a bypass line and the ST-II membrane system. Throttling valves on the bypass line and the membrane feed line were used to control flow through the respective process piping. A valve on the concentrate line of the ST-II was used to maintain a constant pressure on the membrane system. The temperature was controlled using heaters located in the feed tank, along with a heat exchanger on the feed bypass line.

The die lube separated from the feed solution must be concentrated to a 20X level (90^{+}% water removal) for recycling into the die casting machines. To allow testing up to 50X concentration (i.e., 100 gallons reduced to 2 gallons, 98^{+}%), a 500-gallon polyethylene feed tank was installed at the Metaldyne plant. The system's dead or "hold-up" volume was approximately 5 gallons, so at the end of the 50X experiment just enough concentrated feed solution remained to operate the ST-II feed pump and rotors. During normal operations at the 20X level, about 25 gallons typically remained and the membrane rotors and pumps were not threatened with going dry.

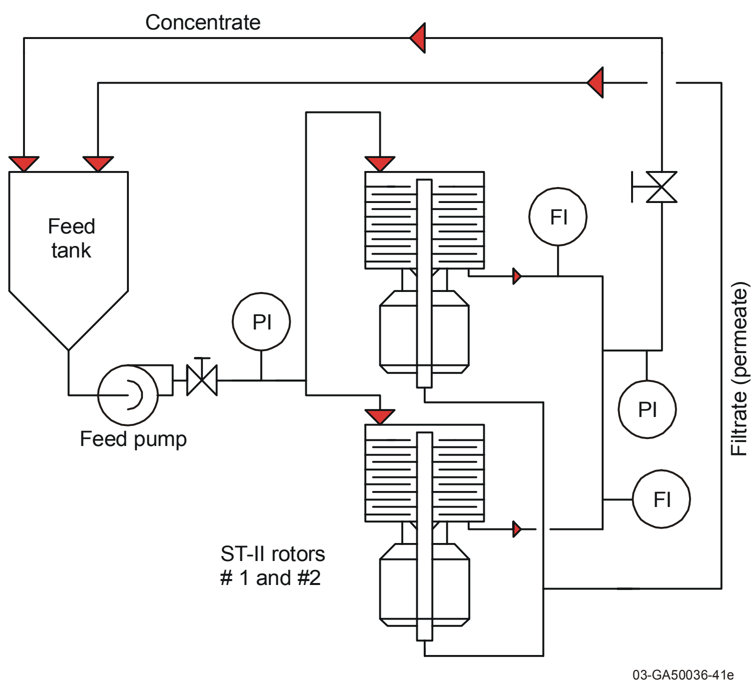


Figure 16. Process flow and instrument diagram for field demonstration system during stabilization. After the membrane fluxes are stable, the filtrate (permeate) line is removed from the feed tank to allow concentration.

The two five-disk rotary filter systems were equipped with ceramic stainless steel composite microfiltration membranes with a pore size of 0.1 microns, supplied by Trumem (Moscow, Russia; available through SpinTek, LLC). The ceramic composite membrane structures were assembled by SpinTek using permeate spacers and Ryton™ disks as previously described.

4.1.1 Concentration Testing Procedure

The feed tank was filled with 500 gallons of fresh die lube wastewater, then the pumps and rotary membrane system were activated. The permeate and concentrate were recycled back to the feed tank until system performance, gauged by membrane fluxes, was stabilized. The permeate line was then withdrawn from the feed tank and placed in the industrial water drain at the plant while the feed solution was concentrated to the target concentration, typically 20X. The concentration was determined volumetrically (i.e., 20X is achieved when 100 gallons is reduced to 5 gallons).

Membrane cleaning needs were determined at the end of each experiment. Membrane cleaning procedures were implemented when the permeation rate fell to approximately 30 gpm.

4.1.2 Chemical Analysis

Chemical analysis for Phase 2 was performed by Nalco Diversified Technologies (NDT, P.O. Box 200 Chagrin Falls, Ohio. NDT has Ohio EPA Certificate #1291 for inorganics and Ohio permit #849 for total coliform). All analyses were performed according to EPA standard methods, typically within 5 days of sampling at Metaldyne. The samples were refrigerated during storage prior to analysis at both Metaldyne and NDT to inhibit biological growth.

4.1.3 Solution Washing of Concentrated Feed Solution to Remove Glycerin

A method of removing glycerin was developed during Phase 2 for possible use in Phase 3. After the die lube solution was concentrated to 20X, the concentrated solution was removed, the ST-II system was flushed with fresh water to establish that the membranes were not fouled, the concentrated the feed solution was returned to the feed tank, and the balance of the volume made up with softened water. The system was then restarted with the concentrate and permeate lines recycled back into the feed tank until a stable flux was achieved. Upon achieving a stable flux, the permeate line was moved to the industrial drain. After 3 h of concentration, the COD level in the permeate stream was 6700 mg/L; after 5.5 h it was 4400 mg/L. This 30% reduction in COD suggests that the glycerin could be washed from the solution prior to recycling the die lube in the plant, which is desirable from the perspective of closed plant recycling.

4.1.4 Membrane Cleaning Process Development

During the early stages of Phase 2, INEEL was requested to develop a cleaning process that removes foulants (the “lipstick” and its associated greases and oils) from the Trumem membranes, supports, and rotary disc shrouds. Suggested cleaners included 2-butoxy-ethanol at elevated temperatures, hot water, and detergent (specifically, Proctor and Gamble’s Dawn™, and “MC-4” a specialized alkaline membrane cleaner supplied by Zenon Environmental, Inc.). We chose to clean the membranes with hot water and Alkanox™ laboratory cleanser as a model for Zenon’s MC-4 membrane cleanser. The results of those efforts are summarized in Table 5.

Table 5. Membrane Cleaning Procedure Developed by INEEL for Trumem Membranes.

Membrane Description	Membrane Condition	Feed: clean water at Temperature (°C)	Feed: clean water at Pressure (psi)	Flux (gfd)	Flux (L/m^2-hr)
Baseline: Virgin Membrane	Virgin	35	45	624	1,062
Used, Supplied by Metaldyne	Fouled	43	45	10.4	17.5
	Fouled	90	45	20	34
	Fouled, soaked in Alcanox Overnight	90	45	155	264.7
Used, Supplied by Metaldyne	Fouled, treated w/ Alcanox	40	40	173.5	294
	Fouled, treated w/ Alcanox	50	40	212.4	360
	Fouled, treated w/ Alcanox	70	40	277.7	459.8
	Fouled, treated w/ Alcanox	85	40	281.1	475.5
	Fouled, treated w/ Alcanox	40	40	210.5	358

Based upon these results, the membranes were cleaned as follows. The commercial caustic MC-4 cleaner (from Zenon Environmental, Inc. Oakville, ON, Canada) was combined with 5 wt% Dawn™ detergent and 5% Cellusolve (ethyleneglycol monobutyl ether, Aldrich Chemicals, Inc.) in clean water in the feed tank. The system was run with the membranes spinning (1100 rpm) at 155-160°F without pressure for 30 to 100 min to wash the surfaces of the membranes. Then pressure was applied (25 psig) and the water flux was observed. If the water flux approached the original water flux (plus or minus 20%), then the membranes were considered clean. The membranes were then rinsed with water. A 5% citric acid rinse to neutralize the surfaces of the membranes was then applied for 30 min, followed by a plain softened water (Culligan, Inc.) rinse for 20 to 40 min. When Metaldyne implemented this cleaning protocol in Phase 3, the oils and greases were removed from the Trumem membranes, and the fluxes approached the manufacturer's original clean water specifications.

4.2 Results and Discussion

The membranes that SpinTek first mounted on the Speedy™ systems were commercial polymer ultrafiltration membranes. These membranes worked well for the initial operational run. However, upon standing in clean or dirty water—for as little as a few minutes—the membranes tended to pucker on the discs. Then, when the membranes started to rotate, they rubbed on the spacers, marking or tearing the surface of the membranes and causing them to become non-selective. Attempts to move the spacers to eliminate rubbing failed. Therefore, we decided to use the stainless steel/ceramic composite membrane materials available from Trumem with 0.1 micron pores. The performance of the Trumem membranes in the pilot concentration studies exceeded our expectations. Fouling was a problem, so we developed cleaning protocols to remove oils, greases, and other foulants from the membranes.

The test data are summarized in Table 6. The following descriptions of each concentration test run present our work verbally and express both the advantages and challenges that were encountered during routine operation of the SpinTek pilot system at Metaldyne's plant.

Concentration Run #1

The initial feed flux with feed solution on the membrane (feed-based flux) for Concentration Run #1 was 34 gfd with a final flux of 38 gfd at the end of the experiment. The feed volume of 655 gallons was reduced 51% to 334 gallons over 9 h of operation. An addition of 50 gallons of city water was made to the feed tank. The flux increased to 45 gfd after 6.5 h. After flushing the membrane system with warm city water, the flux increased to 55 gfd. The system was allowed to stand overnight without water on the membranes.

Following return to service, the flux increased to 101 gfd after 15 min and was then flushed with city water, yielding a flux of 118 gfd. The system was washed for 4 h and the flux started at 44 gfd but was reduced to 41 gfd at the end of the wash. A fresh water flush slightly reduced the flux to 39 gfd. A subsequent wash with plain water for 9 h did not increase the flux nor did a 5 min rinse with soft water. The system was then cleaned with Cellusolve for 30 min. The starting flux was 41 gfd and flux at the completion of the cleaning at 85 gfd. The flux remained at 85 gfd after a 5 min flush with softened water. System pressure remained constant during the test at 50-56 psig inlet pressure and 47 psig on the concentrate.

Table 6. Summary of Concentration Test Results

Test No.	Cleaning[a]	Flux at Start[b]	Flux at End[b]	Final Concentration
1	Cellusolve	34	38	2X
2	Cellusolve, MC-4	164		Water
3	Cellusolve, MC-4	49	46	1.1X
4	Soaked, MC-4, alcohol and glycerin mixture	75	63	20X
5	None	73	54	20X
6	None	61	29	50X
7	None	50	48	20X
8	Cellusolve	91	51	20X
9	None	112	58	20X
10	None	65	62	20X
11	None	48	25	20X

a. This was the solution used to clean the membrane prior to starting the concentration run. MC-4 is an alkaline cleaner.

b. Flux = gallons of filtrate per square foot of membrane over 24 h.

Several factors were considered when these wild variations in flux were observed. First, membrane performance seemed to vary with each operation and, secondly, the need to cleanse the membranes was determined to be rather frequent. Additional research performed at INEEL suggests that a component of the Russian manufactured membranes could be slowly washing out of the membranes, causing the observed variation in flux.

Concentration Run #2

The membranes were cleaned at the end of Run #1. The initial feed-based flux was low, at 25 gfd, and remained there during a short run of 1 h. Pressure during this service run was 54/49 psig (feed/concentrate). The system was flushed and then cleaned with MC-4 (caustic 5%) and Cellusolve (3%) to 32/26 psig. The cleaning lasted 2.25 h and flux increased to 132 gfd. Pressure of the cleaning solution was increased to 52/41 psig and flux increased to 246 gfd. The membranes were then soaked in softened water and the flux remained at 246 gfd. The system was flushed with water at 52/42 psig and the flux decreased to 230 gfd. The system and feed tank were flushed and refilled with water. Hydrochloric acid (5%) was added to the water. At a low pressure of 32/25 psig, the flux started at 164 gfd and ended at 246 gfd after 2 h. Pressure was increased to 42/32 psig and the permeate flow was too high to measure by the flow meters. After 5 min the pressure was increased to 52/39 psig and the flux dropped to 396 gfd. The test was ended when a case bolt on one of the ST-II systems began to leak.

Concentration Run #3

The membranes were flushed with water for 25 min at 58/37 psig with a starting flux of 58 gfd. Fresh feed (500 gallons) was introduced into the feed tank. The feed was introduced at 59/38 psig and the system ran for 2.5 h with an average flux of 55 gfd. The system was flushed with softened water and allowed to stand overnight. The initial 500 gallons of feed had been reduced to 450 gallons in the initial 2.5 h of operation. The system was restarted in the morning and operated for 6.25 h at 48/31 psig and flux was stable at 49 gfd. The system was flushed with water and allowed to stand over night with water on the membranes. The system was restarted 8 –10 h later (in the morning) and operated for 7 h at 48/31 psig; flux was stable at 46 gfd. Further tests were performed with apparently low fluxes but this was due to one of the rotors not operating due to a blown fuse, which the operators did not know until completion of the test. Test #3 ended with an unremarkable die lube solution concentration of 1.4X.

Concentration Run #4

Prior to Concentration Run #4, the membrane disks were removed from the system and hand washed with a Safety-Kleen solvent, MC-4 (alkaline cleaner), and an alcohol/glycerin solution. The membranes were reinstalled, followed by system flushing with water for 10 min. The resulting flux was 163 gfd at 76/52 psig.

The feed tank was filled with 500 gallons of fresh feed and concentrated to 25 gallons (20X) over 26 h of continuous operation. The pressure was 50/34 psig with an initial flux of 75 gfd. The final flux was 63 gfd. The system was flushed with water; the flux returned to 135 gfd after 2 min.

Concentration Run #5

The membranes were only flushed with water, not cleaned, after the previous experiment. A 500 gallon feed solution was reduced to 25 gallons with pressure at 50/35 psig. The initial flux was 73 gfd and final flux was 54 gfd. The system was flushed with water with the flux returning to 97 gfd at a pressure of 42/28 psig. When the pressure was increased to 50/35 psig, the flux increased to 135 gfd, thereby showing that the membranes were clean.

Concentration Run #6 (50X Concentration Experiment)

Concentration Run #6 began without cleaning the membranes as they were demonstrated to be clean at the end of Test Run #5. The run started with 500 gallons of fresh feed, which was reduced to 10 gallons (50X) during the run. Pressure was 50/35 psig though most of the test. The flux started at 61 gfd and continually rose to 81 gfd until 6X concentration of the feed was accomplished. The flux then continuously decreased to 52 gfd at 20X and finally to 29 gfd at 50X. The entire concentration run lasted 32 h. The system was flushed with water for 5 min and the flux was 31 gfd, indicating significant fouling of the membranes. The membranes were flushed with Safety-Kleen solvent followed by water, with the flux returning to 128 gfd at 50/35 psig. The membranes were allowed to stand in softened water awaiting the next experiment.

Concentration Run #7

For Concentration Run #7, 500 gallon of fresh feed solution was added to the feed tank and concentrated to 25 gallons (20X). The flux started at 50 gfd and ended the run at 48 gfd. Pressure started at 50/33 psig and decreased to 42/29 psig at 1.2X for unknown reasons. The entire concentration test lasted 36 h. The membranes were flushed with water and flux increased to 105 at 50/35 psig. The membranes were then soaked in butyl cellosolve for 10 min, followed by water rinsing with the flux increasing to 237 at 50/33 psig, indicating very clean membranes. The membranes were allowed to stand in softened water awaiting the next experiment.

Concentration Run #8

For Concentration Run #8, a fresh 500 gallon feed sample was concentrated to 25 gallons (20X). The flux was initially 91 gfd and ended the run at 51 gfd at a pressure of 50/21 psig. It was later determined that the low concentrate pressure of 21 was an incorrect reading by a faulty pressure gauge. The entire concentration run lasted 35 h. The membranes were flushed with water and flux increased to 109 gfd at 50/21 psig, indicating reasonably clean membranes. The membranes were allowed to stand in softened water awaiting the next experiment.

Concentration Run #9

Concentration Run #9 was initiated with a fresh 500 gallon sample of feed that was reduced to 25 gallons (20X). The initial flux was 112 gfd and final flux was 58 gfd at a pressure of 50/35 psig. The entire concentration run lasted 22 h. The membranes were flushed with water and flux increased to 83 gfd at 50/35 psig. The membranes were allowed to stand in softened water awaiting the next experiment.

Concentration Run # 10

Concentration Run #10 started with 500 gallons of fresh feed, which was reduced to 25 gallons (20X). Pressure was 50/35 psig throughout the test run. The entire concentration run lasted 29 h. Initial flux was 65 gfd and final flux was 62 gfd at a concentration of 20X. After completion of Test Run #10, the system was flushed with water for 5 min and the flux was 31 gfd, indicating membrane fouling. The membranes were allowed to stand in softened water awaiting the next experiment.

Concentration Run #11

Concentration Run #11 was started without cleaning the membranes from Test Run #10. As previously, the run started with 500 gallons of fresh feed and was reduced to 25 gallons (20X). The entire concentration run lasted 47 h. Pressure was 50/35 psig though the Test Run #11. Initial flux was 48 gfd and final flux was 25 gfd at a concentration of 20X. The system was flushed with water for 5 min and the flux was 39 gfd, indicating membrane fouling.

At this point a vigorous cleaning regimen was implemented on the membranes. The system was first flushed with water at 50/35 psig, the flux was 32 gfd. The membranes were then cleaned with MC-4, and the flux dropped to 6 gfd at 50/35 psig. The system was flushed with water at 50/35 psig and the flux increased to 25 gfd. The system was then cleaned with Ultrasil™ solvent (4 butoxy ethanol, Ultrasil, Corp.) for 16 min and the flux increased to 151 gfd. After the Ultrasil™ cleaning, the system was flushed with water to remove the Ultrasil, and the clean water flux was 177 gfd at 50/36 psig, indicating clean membranes. The balance of Test #11 was then completed. At the completion of Test #11 the membranes were rinsed with clean water and the clean water flux decreased very slightly to 174 gfd.

4.3 Summary of Phase 2 Concentration Tests

In tests at Metaldyne's plant, we successfully concentrated the die lube solution to the expected 20X concentration and even as high as 50X. However, at 50X process reliability was difficult to maintain, membrane life was limited, and permeate quality was poor. We concluded that 50X is impractical for commercial implementation. At 20X, the equipment was reliable, the quality of permeate was acceptable, and solids removal was accomplished to support reuse.

5. PHASE 3: FIELD DEMONSTRATION OF DIE LUBE RECYCLING

During the casting operation, the die lube becomes contaminated with glycerin from the hydraulic systems of the casting machinery. When the machines are washed, die lube enters the wastewater stream. The die lube must be removed from the wastewater and, if the lube is to be recycled, the glycerin must be removed from the die lube. Because glycerin is water soluble, we expected it to pass through the membrane of the rotary microfilter and be flushed away from the water-insoluble (oily) components of die lube. The purpose of Phase 3 was to determine if the die lube could be recycled from the wastewater and be directly reinjected into the die casting machinery.

5.1 Concentrating Die Lube and Removing Glycerin

5.1.1 Experimental Procedure

The first step in recycling die lube is to collect the mixture of die lube applied to the die as well as the wash-down waters used to clean the die and other plant equipment. Experimentally, we determined that concentrating this feed solution by 70% (100 gallons become 30 gallons, or 3.3X) is optimal for subsequent washing of the glycerin from the die lube solution. After the 70% concentration was achieved, the rotary filter continued to operate and fresh soft water was added to the feed tank to selectively wash out (diafiltration) the glycerin. When the glycerin was washed out, the concentrated die lube was transferred to another tank for remixing and reintroduction into the die casting machine.

To begin each batch, 500 gallons of fresh die lube wastewater was added to the feed tank of the Speedy™ rotary microfilter system used in Phase 2. Concentration began, with the filtrate being sent to the drain and the concentrate back to the feed tank. More fresh wastewater was added to the feed tank to replace the filtrate sent to the drain until the feed tank concentration reached 70%. At that point, softened water was added to the feed tank. The amount of water required to "wash" out the glycerin varied depending on the amount of glycerin in the concentrated feed solution. Once the concentrated die lube was free of glycerin, it was directly transferred to another tank for remixing and reuse in the die casting machine. For Phase 3, the rotary microfilter operated continuously for six weeks, producing recycled, washed die lube for reuse in the die casting operations.

5.1.2 Results

Biosolutions, LLC (10180 Queensway #6, Chagrin Falls, OH 44023) performed the chemical analyses for Phase 3. The COD of the wastewater solution, after concentration by 70%, varied between 12,000 and 15,000 mg/L. After washing with soft water, the COD was reduced to 1,500 to 2,000 mg/L. This reduction was attributed to removal of small, soluble, organic chemicals, primarily glycerin.

The results of Phase 3 recycling runs are summarized in Figures 17 and 18 and Table 7, presented in more detail in the appendix, and discussed below.

Recycling Run #1

The flux for the die lube wastewater feed solution was initially 124 gfd and declined to 94 gfd at completion of the concentration operation, when the die lube feed was concentrated by 69% or about 3.3X. The die lube feed was then washed with a volume of soft water equal to 70% of the total concentrated feed volume. During washing, the membrane flux increased from 94 to 98 gfd. The COD of the die lube wastewater feed, initially 12,300 mg/L, was reduced to 7,240 mg/L. Upon completion of solution washing, the membranes were flushed with water; the flux returned to 147 gfd.

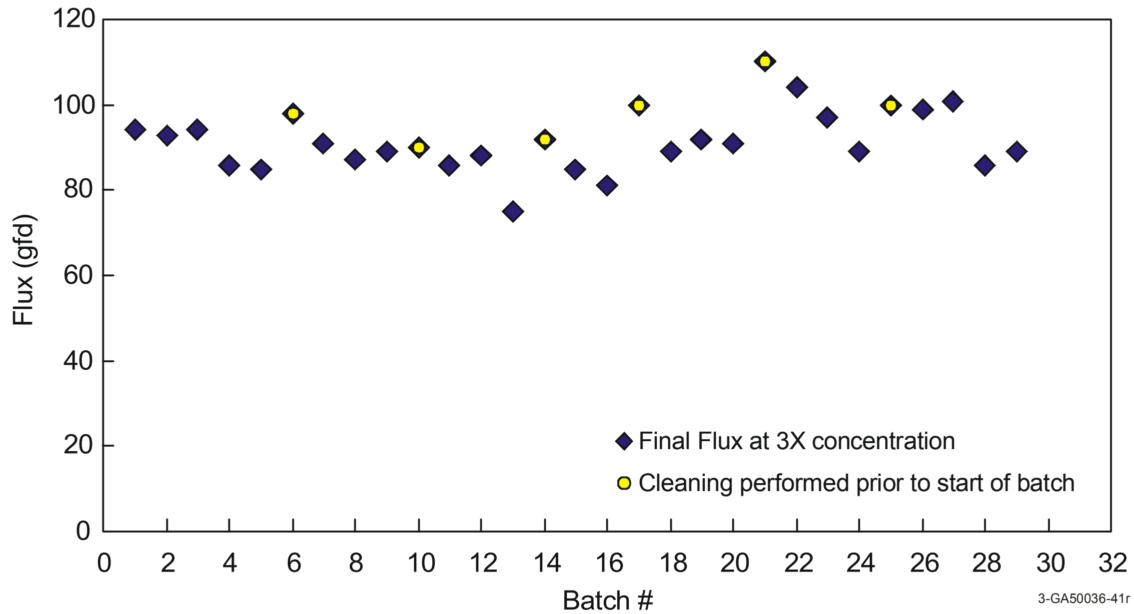


Figure 17. Performance plot for rotary filter of flux versus time during the dewatering of the die lube solution.

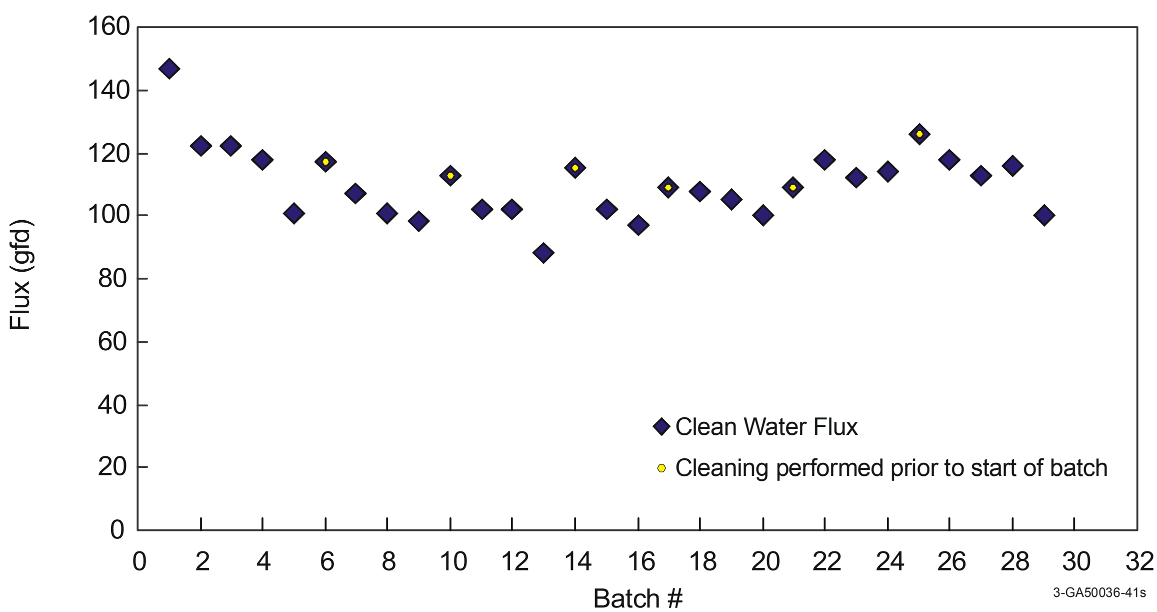


Figure 18. Performance plot for rotary filter during washing (diafiltration).

Table 7. Phase III summary – die lube concentration and recycling runs.

Trial Number	Elapsed Time (hh:mm)	Temperature (°F)	Pressure (psi)		Flow (gpm)		Flux[a] (gfd)	Permeate COD	Con. Total Solids	Sample source	Reduction	Wash Out (%)
			Feed	Concentrate	Feed	Permeate						
1	0:00	76	57	49	6.9	0.860	124		0.80	In flow		
1	16:30	99	48	44	7.6	0.650	94	12300	2.67	In flow	69%	
1	18:25	100	50	45	7.6	0.660	95	12300	2.67	Wash In flow		
1	24:00	100	49	44	7.8	0.680	98	7240	2.13	Wash In flow		65%
1	24:10	74	50	44	8.2	1.020	147			Flush		
2	0:00	78	50	45	7.7	0.700	101		0.72	In flow		
2	18:00	103	49	44	7.5	0.643	93	10600	ND	In flow	69%	
2	18:05	103	49	44	7.5	0.645	93			Wash In flow		
2	28:30	105	49	44	7.2	0.710	102	1520	1.95	Wash In flow		289%
2	28:45	72	45	39	8.3	0.850	122			Flush		
3	0:00	78	51	46	7.3	0.700	101		0.84	In flow		
3	8:00	110	50	44	7.4	0.656	94	12100	2.35	In flow	67%	
3	20:00	105	50	44	7.4	0.680	98	1500	1.82	Wash In flow		320%
3	20:25	80	49	41	8.3	0.850	122			Flush		
4	0:00	80	50	46	6.7	0.640	92		1.07	In flow		
4	12:10	110	49	45	7.1	0.600	86	12240	2.57	In flow	75%	
4	12:10	110	49	45	7.1	0.600	86			Wash In flow		
4	22:25	103	48	45	7.2	0.620	89	2180	ND	Wash In flow		253%
4	22:45	76	49	42	8.4	0.820	118			Flush		

Table 7. (continued).

Trial Number	Elapsed Time (hh:mm)	Temperature (°F)	Pressure (psi) Feed	Pressure (psi) Concentrate	Flow (gpm) Feed	Flow (gpm) Permeate	Flux[a] (gfd)	Permeate COD	Con. Total Solids	Sample source	Reduction	Wash Out (%)
5	0:00	80	50	46	7.0	0.484	70		0.76	In flow		
5	13:00	111	48	44	7.0	0.592	85	11780	2.50	In flow	74%	
5	13:00	111	48	44	7.0	0.593	85			Wash In flow		
5	22:15	109	48	44	7.0	0.592	85	2450	1.93	Wash In flow		216%
5	23:00	72	49	43	8.0	0.698	101			Flush		
5	24:00	84	48	43	8.0	0.745	107			Clean		
5	25:45	82	49	44	9.0	1.800	259			Flush		
6	0:00	80	51	48	8.0	0.943	136		0.64	In flow		
6	11:00	90	50	45	7.0	0.680	98	12600	2.48	In flow	75%	
6	11:00	90	49	45	7.0	0.680	98			Wash In flow		
6	21:45	105	50	45	7.0	0.713	103	2100	2.10	Wash In flow		298%
6	22:30	75	50	45	8.0	0.812	117			Flush		
7	0:00	80	52	48	8.0	0.548	79		0.61	In flow		
7	11:00	112	50	46	7.0	0.635	91	12450	2.16	In flow	72%	
7	11:00	112	50	46	7.0	0.635	91			Wash In flow		
7	26:00	108	50	46	7.0	0.664	96	1240	1.88	Wash In flow		388%
7	26:35	76	48	42	7.0	0.742	107			Flush		
8	0:00	80	52	47	7.0	0.477	69		0.67	In flow		
8	9:00	110	50	46	7.0	0.602	87	10350	1.84	In flow	76%	
8	9:00	110	50	46	7.0	0.602	87			Wash In flow		
8	19:00	108	50	46	7.0	0.622	90	1720	1.55	Wash In flow		250%
8	19:25	72	49	42	8.0	0.703	101			Flush		

Table 7. (continued).

Trial Number	Elapsed Time (hh:mm)	Temperature (°F)	Pressure (psi) Feed	Pressure (psi) Concentrate	Flow (gpm) Feed	Flow (gpm) Permeate	Flux[a] (gfd)	Permeate COD	Con. Total Solids	Sample source	Reduction	Wash Out (%)
9	0:00	80	51	48	7.3	0.448	65		0.67	In flow		
9	13:30	112	53	48	7.3	0.621	89	15920	2.55	In flow	72%	
9	13:30	112	53	49	7.3	0.621	89			Wash In flow		
9	24:35	108	53	48	7.3	0.598	86	2590	1.96	Wash In flow		270%
9	24:45	100	50	42	0.5	1.205	174			Clean		
9	28:45	67	52	43	9.0	1.048	151			Flush		
10	0:00	80	53	47	7.0	0.621	89		0.71	In flow		
10	10:30	108	53	49	7.0	0.623	90	13560	2.35	In flow	72%	
10	10:30	108	53	49	7.0	0.623	90			Wash In flow		
10	22:30	106	53	48	7.0	0.636	92	1510	1.72	Wash In flow		300%
10	22:55	70	53	44	8.0	0.782	113			Flush		
11	0:00	80	56	49	7.0	0.559	80		0.60	In flow		
11	11:00	108	53	48	7.0	0.598	86	13800	1.78	In flow	64%	
11	11:00	108	53	48	7.0	0.598	86			Wash In flow		
11	22:45	100	53	48	7.0	0.574	83	2010	1.35	Wash In flow		335%
11	23:30	110	53	46	8.0	0.286	41			Clean		
11	24:15	70	51	44	9.0	1.011	146			Flush		
12	0:00	70	54	50	7.0	0.722	104		0.73	In flow		
12	12:00	108	53	49	7.0	0.609	88	11800	2.91	In flow	39%	
12	12:00	108	53	49	7.0	0.609	88			Wash In flow		

Table 7. (continued).

Trial Number	Elapsed Time (hh:mm)	Temperature (°F)	Pressure (psi)		Flow (gpm)		Flux[a] (gfd)	Permeate COD	Con. Total Solids	Sample source	Reduction	Wash Out (%)
			Feed	Concentrate	Feed	Permeate						
12	24:00	106	53	48	7.0	0.599	86	1770	2.27	Wash In flow		400%
12	24:30	70	52	44	8.0	0.706	102			Flush		
13	0:00	78	55	50	7.0	0.544	78		0.59	In flow		
13	12:00	110	53	49	7.0	0.522	75	11970	2.09	In flow	67%	
13	12:00	110	53	49	7.0	0.522	75			Wash In flow		
13	24:00	108	53	49	7.0	0.527	76	2080	1.60	Wash In flow		338%
13	24:20	72	52	44	8.3	0.612	88			Flush		
13	24:45	72	53	44	8.0	0.386	56			Clean		
13	27:30	72	51	44	9.3	1.309	188			Flush		
14	0:00	74	53	49	8.0	0.865	125		0.61	In flow	77%	
14	11:45	104	53	48	7.2	0.638	92	12310	2.57	In flow		
14	11:45	100	53	48	7.0	0.638	92			Wash In flow		
14	23:30	100	52	48	7.0	0.647	93	1730	2.22	Wash In flow		300%
14	23:50	72	50	43	8.9	0.802	115			Flush		
15	0:00	72	52	49	8.0	0.593	85		0.60	In flow		
15	12:00	108	52	48	7.0	0.589	85	12320	2.19	In flow	74%	
15	12:00	108	52	48	7.0	0.589	85			Wash In flow		
15	24:00	102	52	48	7.0	0.573	83	1700	1.98	Wash In flow		277%
15	24:20	70	50	43	8.0	0.710	102			Flush		
16	0:00	68	53	49	7.2	0.530	76		0.60	In flow		
16	12:00	106	52	49	7.3	0.561	81	13360	2.12	In flow	73%	

Table 7. (continued).

Trial Number	Elapsed Time (hh:mm)	Temperature (°F)	Pressure (psi)		Flow (gpm)		Flux[a] (gfd)	Permeate COD	Con. Total Solids	Sample source	Reduction	Wash Out (%)
			Feed	Concentrate	Feed	Permeate						
16	12:00	106	52	49	7.0	0.561	81			Wash In flow		
16	24:00	100	52	48	7.0	0.534	77	1975	1.86	Wash In flow		260%
16	24:25	70	50	44	8.3	0.673	97			Flush		
16	25:10	68	56	43	8.4	0.479	69			Clean		
16	27:50	71	51	43	9.0	1.168	168			Flush		
17	0:00	78	53	49	7.8	0.855	123		0.85	In flow		
17	12:45	104	52	48	7.5	0.692	100	8320	3.25	In flow	79%	
17	12:45	104	52	48	7.5	0.692	100			Wash In flow		
17	21:30	99	52	48	7.2	0.680	98	1512	2.72	Wash In flow		250%
17	21:45	84	51	45	8.4	0.760	109			Flush		
18	0:00	76	52	44	7.3	0.619	89		1.23	In flow		
18	13:00	105	52	48	7.3	0.621	89	18840	4.18	In flow	77%	
18	13:00	105	52	48	7.3	0.611	88			Wash In flow		
18	23:00	100	50	48	7.3	0.640	92	3100	3.30	Wash In flow		247%
18	23:15	76	50	43	8.5	0.752	108			Flush		
19	0:00	74	52	49	7.3	0.550	79		0.84	In flow		
19	11:45	104	52	48	7.3	0.638	92	15750	2.92	In flow	75%	
19	11:45	104	52	48	7.3	0.638	92			Wash In flow		
19	22:30	98	50	48	7.5	0.616	89	2100	2.40	Wash In flow		270%
19	22:55	70	50	43	8.7	0.730	105			Flush		

Table 7. (continued).

Trial Number	Elapsed Time (hh:mm)	Temperature (°F)	Pressure (psi)		Flow (gpm)		Flux[a] (gfd)	Permeate COD	Con. Total Solids	Sample source	Reduction	Wash Out (%)
			Feed	Concentrate	Feed	Permeate						
20	0:00	70	52	48	7.1	0.525	76		0.88	In flow		
20	12:45	105	52	48	7.3	0.630	91	15500	3.32	In flow	76%	
20	12:45	105	52	48	7.4	0.630	91			Wash In flow		
20	24:15	100	51	48	7.3	0.606	87	2600	2.90	Wash In flow		280%
20	24:35	78	51	43	8.6	0.695	100			Flush		
20	25:20	137	51	43	9.8	1.650	238			Clean		
20	25:25	78	50	43	9.3	1.050	151			Flush		
21	0:00	75	52	44	9.0	0.820	118		0.84	In flow		
21	10:00	108	52	49	7.8	0.767	110	13500	2.97	In flow	77%	
21	10:00	108	52	49	7.8	0.767	110			Wash In flow		
21	22:00	100	52	49	7.8	0.741	107	1230	2.56	Wash In flow		350%
21	22:30	70	50	4	8.8	0.755	109			Flush		
22	0:00	77	51	47	7.2	0.723	104		0.81	In flow		
22	11:30	109	50	45	7.4	0.725	104	15200	3.63	In flow	78%	
22	11:30	109	50	45	7.4	0.725	104			Wash In flow		
22	23:00	100	50	45	7.7	0.697	100	1640	3.18	Wash In flow		315%
22	23:15	80	49	42	8.7	0.820	118			Flush		
23	0:00	70	51	46	7.4	0.682	98		0.57	In flow		
23	10:45	100	50	46	7.4	0.676	97	12700	2.18	In flow	74%	
23	10:45	100	50	46	7.4	0.676	97			Wash In flow		

Table 7. (continued).

Trial Number	Elapsed Time (hh:mm)	Temperature (°F)	Pressure (psi)		Flow (gpm)		Flux[a] (gfd)	Permeate COD	Con. Total Solids	Sample source	Reduction	Wash Out (%)
			Feed	Concentrate	Feed	Permeate						
23	20:45	92	50	46	7.7	0.684	98	1750	1.77	Wash In flow		295%
23	23:15	75	50	42	8.7	0.780	112			Flush		
24	0:00	70	50	47	7.3	0.686	99		ND	In flow		
24	19:00	100	49	46	7.3	0.619	89	13400	3.55	In flow	84%	
24	19:00	100	49	46	7.3	0.619	89			Wash In flow		
24	24:45	104	49	46	7.4	0.661	95	1700	3.67	Wash In flow		300%
24	25:00	70	49	42	8.4	0.790	114			Flush		
24	36:45	100	50	43	8.3	0.752	108			Clean		
24	39:40	74	49	40	9.9	1.196	172			Flush		
25	0:00	65	50	48	7.2	0.722	104		0.77	In flow		
25	12:00	99	49	46	7.2	0.696	100	14600	2.43	In flow	78%	
25	12:00	96	49	46	7.2	0.696	100			Wash In flow		
25	23:30	96	49	46	7.4	0.715	103	1530	2.87	Wash In flow		328%
25	24:00	70	49	42	8.6	0.874	126			Flush		
26	0:00	70	50	46	7.2	0.630	91		0.98	In flow		
26	11:30	102	49	45	7.4	0.686	99	13800	2.91	In flow	76%	
26	11:30	102	49	46	7.6	0.686	99			Wash In flow		
26	23:30	98	49	45	7.5	0.691	100	1400	2.38	Wash In flow		330%
26	24:00	70	49	42	8.6	0.820	118			Flush		
27	0:00	76	50	46	736.0	0.689	99		0.83	In flow		
27	12:15	108	49	45	7.3	0.700	101	21700	3.19	In flow	78%	

Table 7. (continued).

Trial Number	Elapsed Time (hh:mm)	Temperature (°F)	Pressure (psi)		Flow (gpm)		Flux[a] (gfd)	Permeate COD	Con. Total Solids	Sample source	Reduction	Wash Out (%)
			Feed	Concentrate	Feed	Permeate						
27	12:15	108	49	46	7.3	0.700	101			Wash In flow		
27	24:00	100	49	46	7.3	0.665	96	2150	2.75	Wash In flow		250%
27	24:15	70	49	42	8.5	0.782	113			Flush		
27	24:25	70	50	44	8.3	0.652	94			Clean		
27	26:45	70	48	42	8.9	1.110	160			Flush		
28	0:00	70	50	46	7.4	0.750	108		0.94	In flow		
28	11:00	100	49	45	6.9	0.594	86	14700	3.07	In flow	76%	
28	12:00	100	49	45	7.0	0.580	84			Wash In flow		
28	23:00	100	49	45	6.8	0.631	91	2000	2.61	Wash In flow		285%
28	24:05	70	49	42	8.8	0.804	116			Flush		
29	0:00	68	50	46	7.3	0.606	87		0.81	In flow		
29	10:45	92	50	46	7.8	0.619	89	14800	2.89	In flow	73%	
29	10:45	90	49	46	7.8	0.619	89			Wash In flow		
29	22:00	90	49	45	7.7	0.651	94	1970	2.13	Wash In flow		277%
29	22:20	70	48	42	9.2	0.691	100			Flush		
29	22:25	68	49	44	8.8	0.615	89			Clean		
29	24:55	70	49	42	8.5	1.010	145			Flush		

a. Flux = gallons of filtrate per square foot of membrane over 24 h.

Recycling Run #2

The flux for the die lube wastewater feed solution was initially 101 gfd and declined to 93 gfd at the completion of the concentration operation, when the die lube feed was concentrated by 69%. The die lube feed was then washed with a volume of soft water equal to 107% of the total concentrated feed volume. During washing, the membrane flux was stable at 93 gfd. The COD of the die lube wastewater feed, initially 10,600 mg/L, was reduced to 3,900 mg/L. The die lube wastewater feed was washed with water by an additional 189% and the flux increased from 93 to 102 gfd. The COD of the rewashed die lube wastewater feed was further reduced from 3,900 mg/L to 1,520 mg/L. Upon completion of the experiment, the membranes were flushed with water; the flux was 122 gfd.

Recycling Run #3

The flux for the die lube wastewater feed solution was initially 101 gfd and declined to 94 gfd at the completion of the concentration operation, when the die lube feed was concentrated by 67%. The die lube wastewater feed was then washed with a volume of soft water equal to 320% of the total concentrated feed volume. During washing, the membrane flux increased from 94 to 98 gfd. The COD of the die lube wastewater feed, initially 12,100 mg/L, was reduced to 1,500 mg/L. Upon completion of the experiment, the membranes were flushed with water; the flux returned to 122 gfd.

Recycling Run #4

The flux for the die lube wastewater feed solution was initially 92 gfd and declined to 86 gfd at completion of the concentration operation, when the die lube feed was concentrated by 75%. The die lube wastewater feed was then washed with a volume of soft water equal to 253% of the total concentrated feed volume. During washing, the membrane flux increased from 86 to 89 gfd. The COD of the die lube wastewater feed, initially 12,240 mg/L, was reduced to 2,180 mg/L. Upon completion of the experiment, the membranes were flushed with water; the flux was 118 gfd.

Recycling Run #5

The flux for the die lube wastewater feed solution was initially 70 gfd and increased to 85 gfd at completion of the concentration operation, when the die lube feed was concentrated by 74%. The die lube wastewater feed was then washed with a volume of soft water equal to 216% of the total concentrated feed volume. During washing, the membrane flux increased from 85 to 88 gfd. The COD of the die lube wastewater feed, initially 11,780 mg/L, was reduced to 2,450 mg/L. Upon completion of the experiment, the membranes were flushed with water; the flux was 101 gfd. The system was then cleaned with MC-4 at a pH of 11, 150°F, dissolved in water. After cleaning, the flux of clean water increased to 259 gfd.

Recycling Run #6

The flux for the die lube wastewater feed solution was initially 136 gfd and decreased to 98 gfd at completion of the concentration operation, when the die lube feed was concentrated by 75%. The die lube wastewater feed was then washed with a volume of soft water equal to 298% of the total concentrated feed volume. During washing, the membrane flux increased from 98 to 103 gfd. The COD of the die lube wastewater feed, initially 12,600 mg/L, was reduced to 2,100 mg/L. Upon completion of the experiment, the membranes were flushed with water; the flux was 117 gfd.

Recycling Run #7

The flux for the die lube wastewater feed solution was initially 79 gfd and increased to 91 gfd at completion of the concentration operation, when the die lube feed was concentrated by 73%. The die lube wastewater feed was then washed with a volume of soft water equal to 388% of the total concentrated feed volume. During washing, the membrane flux increased from 91 to 96 gfd. The COD of the die lube wastewater feed, initially 12,450 mg/L, was reduced to 1,240 mg/L. Upon completion of the experiment, the membranes were flushed with water; the flux was 107 gfd.

Recycling Run #8

The flux for the die lube wastewater feed solution was initially 69 gfd and increased to 87 gfd at completion of the concentration operation, when the die lube feed was concentrated by 76%. The die lube wastewater feed was then washed with a volume of soft water equal to 250% of the total concentrated feed volume. During washing, the membrane flux increased from 87 to 90 gfd. The COD of the die lube wastewater feed, initially 10,350 mg/L, was reduced to 1,720 mg/L. Upon completion of the experiment, the membranes were flushed with water; the flux was 101 gfd.

Recycling Run #9

The flux for the die lube wastewater feed solution was initially 65 gfd and increased to 89 gfd at completion of the concentration operation, when the die lube feed was concentrated by 72%. The die lube wastewater feed was then washed with a volume of soft water equal to 270% of the total concentrated feed volume. During washing, the membrane flux decreased from 89 to 86 gfd. The COD of the die lube wastewater feed, initially 15,920 mg/L, was reduced to 2,590 mg/L. The membranes were cleaned with MC-4 at a pH of 11, 150°F, dissolved in water. After cleaning, the flux of clean water increased to 151 gfd.

Recycling Run #10

The flux for the die lube wastewater feed solution was initially 89 gfd and increased to 90 gfd at completion of the concentration operation, when the die lube feed was concentrated by 72%. The die lube wastewater feed was then washed with a volume of soft water equal to 300% of the total concentrated feed volume. During washing, the membrane flux increased from 90 to 92 gfd. The COD of the die lube wastewater feed, initially 13,560 mg/L, was reduced to 1,510 mg/L. Upon completion of the experiment, the membranes were flushed with water; the flux was 113 gfd.

Recycling Run #11

The flux for the die lube wastewater feed solution was initially 80 gfd and increased to 86 gfd at completion of the concentration operation, when the die lube feed was concentrated by 64%. The die lube wastewater feed was then washed with a volume of soft water equal to 335% of the total concentrated feed volume. During washing, the membrane flux decreased from 86 to 83 gfd. The COD of the die lube wastewater feed, initially 13,800 mg/L, was reduced to 2,010 mg/L. The membranes were cleaned with MC-4 at a pH of 11, 150°F, dissolved in water. After cleaning, the flux of clean water increased to 146 gfd.

Recycling Run #12

The flux for the die lube wastewater feed solution was initially 104 gfd and decreased to 88 gfd at completion of the concentration operation, when the die lube feed was concentrated by 67%. The die lube wastewater feed was then washed with a volume of soft water equal to 400% of the total concentrated feed volume. During washing, the membrane flux decreased from 88 to 86 gfd. The COD of the die lube wastewater feed, initially 11,800 mg/L, was reduced to 1,770 mg/L. After washing was complete, the membranes were flushed with water; the flux was 102 gfd.

Recycling Run #13

The flux for the die lube wastewater feed solution was initially 78 gfd and decreased to 75 gfd at completion of the concentration operation, when the die lube feed was concentrated by 67%. The die lube wastewater feed was then washed with a volume of soft water equal to 338% of the total concentrated feed volume. During washing, the membrane flux increased from 75 to 76 gfd. The COD of the die lube wastewater feed, initially 11,970 mg/L, was reduced to 2,080 mg/L. The system was then cleaned with MC-4 at a pH of 11, 150°F, dissolved in water. After cleaning, the flux of clean water increased to 188 gfd.

Recycling Run #14

The flux for the die lube wastewater feed solution was initially 125 gfd and decreased to 92 gfd at completion of the concentration operation, when the die lube feed was concentrated by 77%. The die lube wastewater feed was then washed with a volume of soft water equal to 300% of the total concentrated feed volume. During washing, the membrane flux increased from 92 to 93 gfd. The COD of the die lube wastewater feed, initially 12,310 mg/L, was reduced to 1,730 mg/L. Upon completion of the experiment, the membranes were flushed with water; the flux was 115 gfd.

Recycling Run #15

The flux for the die lube wastewater feed solution was 85 gfd at the start and completion of the concentration operation, when the die lube feed was concentrated by 74%. The die lube wastewater feed was then washed with a volume of soft water equal to 277% of the total concentrated feed volume. During washing, the membrane flux decreased from 85 to 83 gfd. The COD of the die lube wastewater feed, initially 12,320 mg/L, was reduced to 1,700 mg/L. Upon completion of the experiment, the membranes were flushed with water; the flux was 102 gfd.

Recycling Run #16

The flux for the die lube wastewater feed solution was initially 76 gfd and increased to 81 gfd at completion of the concentration operation, when the die lube feed was concentrated by 73%. The die lube wastewater feed was then washed with a volume of soft water equal to 260% of the total concentrated feed volume. During washing, the membrane flux decreased from 81 to 77 gfd. The COD of the die lube wastewater feed, initially 13,360 mg/L, was reduced to 1,975 mg/L. The system was then cleaned with MC-4 at a pH of 11, 150°F, dissolved in water. After cleaning, the flux of clean water increased to 168 gfd.

Recycling Run #17

The flux for the die lube wastewater feed solution was initially 123 gfd and decreased to 100 gfd at completion of the concentration operation, when the die lube feed was concentrated by 79%. The die lube wastewater feed was then washed with a volume of soft water equal to 250% of the total concentrated feed volume. During washing, the membrane flux increased from 82 to 83 gfd. The COD of the die lube wastewater feed, initially 8320 mg/L, was reduced to 1,512 mg/L. Upon completion of the experiment, the membranes were flushed with water; the flux was 109 gfd.

Recycling Run #18

The flux for the die lube wastewater feed solution was 89 gfd at the start and completion of the concentration operation, when the die lube feed was concentrated by 77%. The die lube wastewater feed was then washed with a volume of soft water equal to 274% of the total concentrated feed volume. During washing, the membrane flux increased from 88 to 92 gfd. The COD of the die lube wastewater feed, initially 18,840 mg/L, was reduced to 3,100 mg/L. Upon completion of the experiment, the membranes were flushed with water; the flux was 108 gfd.

Recycling Run #19

The flux for the die lube wastewater feed solution was initially 79 gfd and increased to 92 gfd at completion of the concentration operation, when the die lube feed was concentrated by 75%. The die lube wastewater feed was then washed with a volume of soft water equal to 270% of the total concentrated feed volume. During washing, the membrane flux decreased from 92 to 89 gfd. The COD of the die lube wastewater feed, initially 15,750 mg/L, was reduced to 2,100 mg/L. Upon completion of the experiment, the membranes were flushed with water; the flux was 105 gfd.

Recycling Run #20

The flux for the die lube wastewater feed solution was initially 76 gfd and increased to 91 gfd at completion of the concentration operation, when the die lube feed was concentrated by 76%. The die lube wastewater feed was then washed with a volume of soft water equal to 280% of the total concentrated feed volume. During washing, the membrane flux decreased from 91 to 87 gfd. The COD of the die lube wastewater feed, initially 15,500 mg/L, was reduced to 2,600 mg/L. The system was then cleaned with MC-4 at a pH of 11, 150°F, dissolved in water. After cleaning, the flux of clean water increased to 238 gfd, with the final flush clean water flux of 151 gfd.

Recycling Run #21

The flux for the die lube wastewater feed solution was initially 118 gfd and decreased to 110 gfd at completion of the concentration operation, when the die lube feed was concentrated by 77%. The die lube wastewater feed was then washed with a volume of soft water equal to 350% of the total concentrated feed volume. During washing, the membrane flux decreased from 110 to 107 gfd. The COD of the die lube wastewater feed, initially 13,500 mg/L, was reduced to 1,230 mg/L. Upon completion of the experiment, the membranes were flushed with water; the flux was 109 gfd.

Recycling Run #22

The flux for the die lube wastewater feed solution was 104 gfd at the start and completion of the concentration operation, when the die lube feed was concentrated by 78%. The die lube wastewater feed was then washed with a volume of soft water equal to 315% of the total concentrated feed volume. During washing, the membrane flux decreased from 104 to 100 gfd. The COD of the die lube wastewater feed, initially 15,200 mg/L, was reduced to 1,640 mg/L. Upon completion of the experiment, the membranes were flushed with water; the flux was 118 gfd.

Recycling Run #23

The flux for the die lube wastewater feed solution was initially 98 gfd and increased to 97 gfd at completion of the concentration operation, when the die lube feed was concentrated by 74%. The die lube wastewater feed was then washed with a volume of soft water equal to 295% of the total concentrated feed volume. During washing, the membrane flux increased from 97 to 98 gfd. The COD of the die lube wastewater feed, initially 12,700 mg/L, was reduced to 1,750 mg/L. Upon completion of the experiment, the membranes were flushed with water; the flux was 112 gfd.

Recycling Run #24

The flux for the die lube wastewater feed solution was initially 99 gfd and decreased to 89 gfd at completion of the concentration operation, when the die lube feed was concentrated by 83%. The die lube wastewater feed was then washed with a volume of soft water equal to 300% of the total concentrated feed volume. During washing, the membrane flux increased from 89 to 95 gfd. The COD of the die lube wastewater feed, initially 13,400 mg/L, was reduced to 1,700 mg/L. The system was then cleaned with MC-4 at a pH of 11, 150°F dissolved in water. After cleaning, the flux of clean water increased to 172 gfd.

Recycling Run #25

The flux for the die lube wastewater feed solution was initially 104 gfd and decreased to 100 gfd at completion of the concentration operation, when the die lube feed was concentrated by 77%. The die lube wastewater feed was then washed with a volume of soft water equal to 328% of the total concentrated feed volume. During washing, the membrane flux decreased from 100 to 103 gfd. The COD of the die lube wastewater feed, initially 14,600 mg/L, was reduced to 1,530 mg/L. Upon completion of the experiment, the membranes were flushed with water; the flux was 126 gfd.

Recycling Run #26

The flux for the die lube wastewater feed solution was initially 91 gfd and increased to 99 gfd at completion of the concentration operation, when the die lube feed was concentrated by 76%. The die lube wastewater feed was then washed with a volume of soft water equal to 330% of the total concentrated feed volume. During washing, the membrane flux increased from 99 to 100 gfd. The COD of the die lube wastewater feed, initially 13,800 mg/L, was reduced to 1,400 mg/L. Upon completion of the experiment, the membranes were flushed with water; the flux was 118 gfd.

Recycling Run #27

The flux for the die lube wastewater feed solution was initially 99 gfd and increased to 101 gfd at completion of the concentration operation, when the die lube feed was concentrated by 77%. The die lube wastewater feed was then washed with a volume of soft water equal to 250% of the total concentrated feed volume. During washing, the membrane flux decreased from 101 to 96 gfd. The COD of the die lube wastewater feed, initially 21,700 mg/L, was reduced to 2,150 mg/L. The membranes were cleaned after this recycling run because extra time was available, not because of low fluxes. The system was cleaned with MC-4 at a pH of 11, 150°F, dissolved in water. After cleaning, the flux of clean water increased to 160 gfd.

Recycling Run #28

The flux for the die lube wastewater feed solution was initially 108 gfd and decreased to 86 gfd at completion of the concentration operation, when the die lube feed was concentrated by 76%. The die lube wastewater feed was then washed with a volume of soft water equal to 285% of the total concentrated feed volume. During washing, the membrane flux increased from 84 to 91 gfd. The COD of the die lube wastewater feed, initially 14,700 mg/L, was reduced to 2,000 mg/L. Upon completion of the experiment, the membranes were flushed with water; the flux was 116 gfd.

Recycling Run #29

The flux for the die lube wastewater feed solution was initially 87 gfd and increased to 89 gfd at completion of the concentration operation, when the die lube feed was concentrated by 73%. The die lube wastewater feed was then washed with a volume of soft water equal to 277% of the total concentrated feed volume. During washing, the membrane flux increased from 89 to 94 gfd. The COD of the die lube wastewater feed, initially 14,800 mg/L, was reduced to 1,970 mg/L. The system was then cleaned with MC-4 at a pH of 11, 150°F, dissolved in water. After cleaning, the flux of clean water increased to 145 gfd.

5.2 Die Casting with Recycled Die Lube

A test methodology for reuse of the solids in the casting process was established. A short-term test was performed with good results, so a long-term test was developed. General comments, descriptions, and results of these tests are presented below.

5.2.1 Plant Operation

Metaldyne's Twinsburg plant produces aluminum castings for automotive transmissions. It's process is considered best-in-class for cast / trim / ship facilities. Molten ASTM A-380 aluminum is auto-ladled into the chamber/sleeve at 1,190^{o}F. Die lubricant, an oil and water emulsion, provides cooling and release. After trim and inspection, automated handling conveyors process parts into a steel grit shot blast machine for final finishing. Final inspection, basket loading, and loading into delivery trucks is sometimes accomplished in one hour.

The die lube is purchased in a concentrate and diluted to suit the process needs. Sixty to seventy ounces of lubricant are sprayed onto the dies per casting cycle (Figure 19). This lubricant is mixed / atomized with 100 psi air and delivered to specified die locations through nozzles located on the manifold (see Figure 20).

The plant's drainage system is designed to accept all liquids from the foundry operations. While the primary waste generated from the casting process is die lubricant, other ingredients enter into the plant piping. Items such as detergents from washing operations, various way oils, greases, and glycol used to maintain the casting machinery are drained into the plant's water treatment system. Also some "process cooling" water and cooling tower bleed are piped into the treatment system.

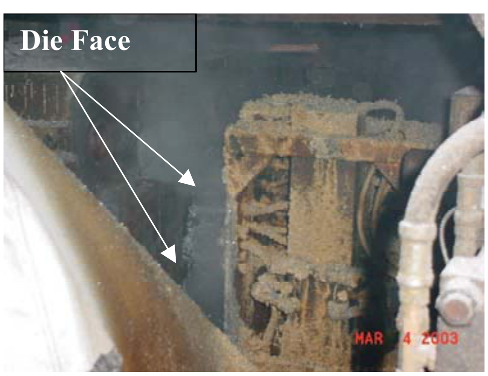


Figure 19. Die face where lube is applied.

Figure 20. Spray manifold for applying die lube.

5.2.2 Test Procedure

For this test, the water from the casting operation was isolated using several tanks, mechanical interconnections, and control valves. The first treatment step was to remove free oils and greases using rope skimmers and dissolved air floatation. Next, the water was run through the Speedy™ active-membrane rotary microfilter system, which separated the unwanted pollutants and dilution water from the die lubricant. The concentrated die lubricant was re-diluted using total solids as a test measure. This re-established the concentration of solids to that of the original die lubricant. Where needed, bacteria control was implemented to maintain product integrity. Batches mixed from 50% recycled lubricant and 50% new lubricant were delivered to the casting machine each day. Mixing new and recycled lubricant was a conservative approach designed to provide the casting operation's management with some confidence during testing.

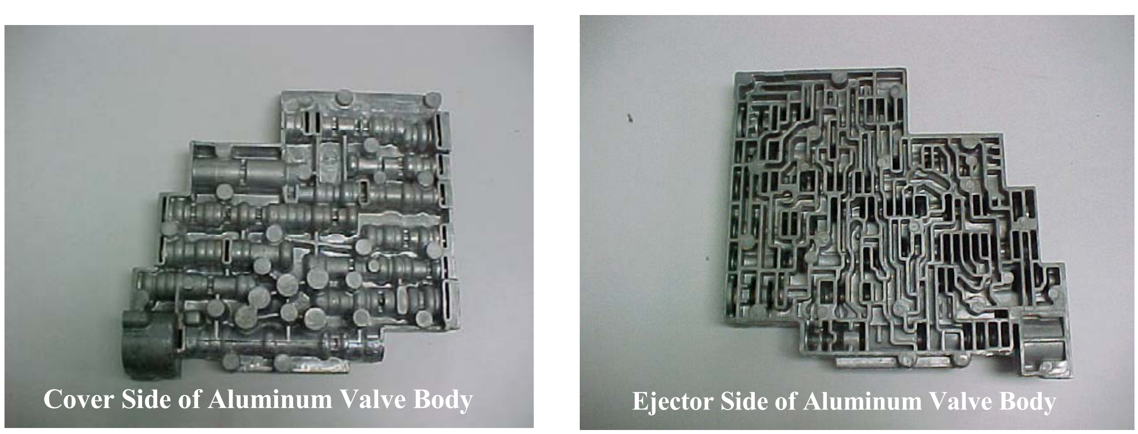
The die casting machine used in this test makes aluminum valve-control body castings known as "Job-1094." This casting process for this product exemplifies the most extreme demands on the die lubricant. In this process, die cooling, mold release characteristics, and resistance to metal adhesion (or soldering) are most critical, in comparison to various other aluminum castings.

The Job-1094 casting, shown in Figure 21 and further described in Table 8, is roughly 10.5 in. square. It is predominantly 1.25 in. thick, with one large feature shown in the lower left of Figure 21a that has a thickness of 2.25 in. Because of the features and details of this part, the projected surface area of the casting and related tool steel is great in comparison to the simple square area of this part. The picture on the right is the most extreme example of this. As a result, tool release, metal adhesion, and high temperature soldering are critical challenges.

5.2.3 Casting Results

Test data and quality records indicate that the scrap was reduced from 8.4% to 7.8%. No statistical analysis has been conducted to evaluate the significance of this change.

A slight increase in tooling (measured in cost per unit of production) was observed. This was influenced significantly by tool breakage that occurred during this test. This has been evaluated and cannot be related to the die lubricant. On September 13, two months into the test, a casting was not lifted cleanly by the extractor robot, it was left on/in the die and the die halves re-closed crushing this piece and related die details. The immediate repairs to the die were completed. Some additional die damage around the "bridge area" was not considered detrimental. Several days later, further deterioration to the bridge area required additional die repairs.



a. b.

Figure 21. Aluminum valve body cast with recycled die lube.

Table 8. Test Casting Job 1094.

Test part:	Aluminum Valve-Control body
Material:	ASTM, A380
Customer:	General Motors Power Train
General Motors Power Train Assembly:	Part No. 4L60E
Poured Weight:	9.8Lbs
Part Weight:	6.5Lbs
Injection Temp:	1180-1205^{o}F
Testing Period:	July 12, 2002 to Sept. 23, 2002.
Die Cast Machine No. 11	
Job number 1094	
Cavity #17 (i.e., Die #17, consisting of two halves, “Cover” and “Ejector”)	

5.2.4 Casting Results

Test data and quality records indicate that the scrap was reduced from 8.4% to 7.8%. No statistical analysis has been conducted to evaluate the significance of this change.

A slight increase in tooling (measured in cost per unit of production) was observed. This was influenced significantly by tool breakage that occurred during this test. This has been evaluated and cannot be related to the die lubricant. On September 13, two months into the test, a casting was not lifted cleanly by the extractor robot, it was left on/in the die and the die halves re-closed crushing this piece and related die details. The immediate repairs to the die were completed. Some additional die damage around the “bridge area” was not considered detrimental. Several days later, further deterioration to the bridge area required additional die repairs.

5.3 Summary of Phase 3 Recycling Tests

Phase 3 was a continuous six-week test that demonstrated the SpinTek system’s ability to concentrate, wash, and recycle the die lube solution at the Metaldyne plant. Die lube was continually concentrated and the COD reduced by a factor of 8 to 10, which is attributed to successfully washing glycerin from the die lube. The die lube was then recycled in a production die-casting machine. Test data and quality records indicate that scrap from the die casting operation was reduced from 8.4% to 7.8%.

The two Speedy™ rotary filters operated continuously for six weeks without any down time due to mechanical or electrical failure. The membranes showed no apparent damage due to abrasion or the effects of the die lube solution. Only seven cleaning cycles were required to maintain filtrate throughput. Several experimental runs were conducted without prior cleaning, which demonstrated that it would not be necessary to clean the membranes between campaigns in full-scale implementation of the system. This is desirable because cleaning generates waste.

There is no doubt that this full-scale production test yielded tremendous results. We established that Metaldyne’s die lubricant can be concentrated, washed, and recycled. Further evaluation is needed to determine if this process is cost effective.

6. DISCUSSION

Laboratory testing, using small, flat, sheet membranes and a bench-scale rotary filter, demonstrated that active-surface membrane technology was a good candidate for field testing at Metaldyne's plant. The metals content of the feed solutions was reduced significantly using tight ultrafiltration active-surface membranes. However, significant hydro-gel-like precipitates formed in the permeate solutions upon standing. The gels may be hydrated aluminum and iron oxy-/hydroxy-species. These gels are very pH sensitive and dissolved immediately with drop-wise additions of acid to 1-L samples. Nanofiltration to polish the effluent concentrated the metal ions slightly. The results of the experiments were encouraging because permeates from the nanofiltration system are clear, colorless, and show only slight discoloration and no significant gel precipitation upon standing

At Metaldyne's plant, we successfully concentrated the die lube solution to the expected 20X concentration, and even as high as 50X, using two rotary membrane systems built by SpinTek, LLC. Although the solution could be concentrated to 50X, the low flux of the membrane between 20X and 50X is impractical for commercial applications. Initially, SpinTek mounted commercial polymer ultrafiltration membranes in the Speedy™ units. However, the membranes tended to pucker, leading to wear and loss of selectivity. So we changed to stainless steel/ceramic composite membrane materials manufactured by Trumem Membranes. All of the filtrates were very clear, indicating satisfactory die lube removal by the ceramic membranes. Fouling of the membranes was a problem, and cleaning protocols were developed to remove oils, greases, and other foulants from the membranes.

Phase 3 was a continuous six-week test that demonstrated the SpinTek, LLC system's ability to concentrate, wash, and recycle the die lube solution at the Metaldyne plant. Die lube was continually concentrated and the COD reduced by a factor of 8 to 10, which is attributed to successfully washing glycerin from the die lube. The die lube was then recycled in a production die-casting machine. The two Speedy™ rotary filters operated continuously for six weeks without any down time due to mechanical or electrical failure. The Trumem composite membranes showed no apparent damage due to abrasion or the effects of the die lube solution. Only seven cleaning cycles were required to maintain filtrate throughput. Several experimental runs were conducted without prior cleaning, which demonstrated that it would not be necessary to clean the membranes between every campaign in full-scale implementation of the system. This is desirable because cleaning generates waste. Test data and quality records from the die casting machine, running at full production scale, indicate that production scrap was reduced from 8.4% to 7.8%.

There is no doubt that this project yielded tremendous results. The full-scale production test proved that it is possible to recycle Metaldyne's die lubricant. Further evaluation is needed to determine if it is cost effective to do so.

7. CONCLUSION

The oil and water mixtures produced by Metaldyne's die casting plant can be cleaned up using active-surface membrane technology. Field testing using the ST-II rotary filter/Speedy™ system, for concentration of the die lube from waste water generated during die casting operations and for recycling/recovery of die lube, showed very promising results. The feed solution was concentrated to the target of 20X in seven tests, and one test further concentrated the feed to 50X (throughput from 20X to 50X is too low for commercial use). During all of these tests the filtrate was very clear, indicating nearly complete removal of the die cast material. At the completion of these tests the membranes were cleaned and flux recovered.

When the rotary filter system was used for glycerin removal and die lube solution recycling/reconstitution, the results were also very favorable. This project successfully demonstrated that the rotary microfilter is capable of concentrating the die lube components from the waste stream of a die casting operation, washing out the contaminating glycerin, and producing a die lube suitable for recycling. Manufacturing records indicate that the scrap was reduced from 8.4% to 7.8%. The recycling system operated continuously for six weeks; only seven membrane cleaning cycles were required and the system experienced no down time due to mechanical or electrical failure.

There is no doubt that the field tests yielded tremendous results. They proved that Metaldyne's die lubricant can be recycled. Although further evaluation is needed to determine if it is cost effective for this die lube to be recycled, this project has shown significant opportunities for further evaluation by Metaldyne, the die casting industry, and other industries with similar waste streams.

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Appendix A

Raw and Run Data

Appendix A

Raw and Run Data

This appendix contains the following raw data tables:

Table A-1. STC Tests – 0.15 micron ceramic membrane.

Membrane: 0.15 nominal μ
Surface Area: 0.05
Feed Sample: Sample B
Initial Feed Volume: 3500 mL
Final Feed Volume: 3500 mL
Final Concentrate: 1x
Final Flux: N/A

Operator: Jason Gilmour
Date: 12/20/99

Time of Day (hh:mm)	Elapsed Time (hh:mm)	Feed Flow (gal/min)	Feed Press. (psi)	Conc. Press. (psi)	Feed Temp. (°F)	Permeate Flow (mL/min)	Comments	Flux (gpd/sq ft)
10:30	0:00	1.00	40	34	60	9.90	Initial Perm. Hazy	75.2
10:45	0:15	1.00	40	34	60	9.50		72.2
11:00	0:30	1.00	40	35	62	8.60		65.4
11:15	0:45	1.00	40	34	63	7.80		59.3
11:30	1:00	1.00	40	34	64	7.30		55.5
11:45	1:15	1.00	40	34	66	6.50		49.4
12:00	1:30	1.00	40	33	68	6.00	Clearer Permeate	45.6
12:30	2:00	1.00	40	33	69	5.00		38.0
1:00	2:30	1.00	40	33	69	4.00		30.4
2:00	3:30	1.00	40	33	70	3.10		23.5
2:30	4:00	1.00	40	33	70	2.60		19.8
3:30	5:00	1.00	40	33	70	2.30		17.5
4:30	6:00	1.00	40	33	70	2.10		16.0

Test Stopped Due to low flux

Table A-2. STC Tests – 0.07 micron ceramic membrane.

Membrane: 0.07 nominal μ
Surface Area: 0.05
Feed Sample: Sample B
Initial Feed Volume: 3500 mL
Final Feed Volume: 3500 mL
Final Concentrate: 1x
Final Flux: N/A

Operator: Jason Gilmour
Date: 12/27/99

Time of Day (hh:mm)	Elapsed Time (hh:mm)	Feed Flow (gal/min)	Feed Press. (psi)	Conc. Press. (psi)	Feed Temp. (°F)	Permeate Flow (mL/min)	Comments	Flux (gpd/sqft)
9:00	0:00	1.00	40	36	61	6.00		45.6
9:15	0:15	1.00	40	36	61	5.80	Clear Permeate Throughout Test	44.1
9:30	0:30	1.00	40	35	61	5.00		38.0
9:45	0:45	1.00	40	35	61	4.70		35.7
10:00	1:00	1.00	40	35	62	4.50		34.2
10:15	1:15	1.00	40	34	62	4.30		32.7
10:30	1:30	1.00	40	34	62	4.20		31.9
10:45	1:45	1.00	40	34	63	4.10		31.2
11:15	2:15	1.00	40	34	63	4.00		30.4
11:45	2:45	1.00	40	34	63	3.80		28.9
12:15	3:15	1.00	40	34	64	3.70		28.1
12:45	3:45	1.00	40	34	64	3.60		27.4
1:15	4:15	1.00	40	34	65	3.50		26.6
2:15	5:15	1.00	40	34	66	3.40		25.8
3:15	6:15	1.00	40	34	67	3.30		25.0
4:15	7:15	1.00	40	34	67	3.20		24.3
8:00	22:45	1.00	40	34	62	1.80		13.7
9:00	23:45	1.00	40	34	62	1.70		12.9
2:00	4:00	1.00	40	34	66	1.40		10.6

Test Stopped Due to Low Flux

Table A-3. STC Tests – 100,000 MW cutoff polymeric membrane.

Membrane: Polymeric PVFD
Surface Area: 0.05
Feed Sample: Sample B
Initial Feed Volume: 3500 mL
Final Feed Volume: 850 mL
Final Concentrate: 4x
Final Flux: 41 gpd/sqft

Operator: Jason Gilmour
Date: 12/29/99

Time of Day (hh:mm)	Elapsed Time (hh:mm)	Feed Flow (gal/min)	Feed Press. (psi)	Conc. Press. (psi)	Feed Temp (°F)	Permeate Flow (mL/min)	Comments	Flux (gpd/sq ft)
2:15	0:00	1.00	25	18	66	7.90		60.0
2:30	0:15	1.00	25	18	66	7.20	Clean Clear Permeate Throughout test	54.7
2:45	0:30	1.00	25	18	67	7.00		53.2
3:00	0:45	1.00	25	18	68	7.00		53.2
3:15	1:00	1.00	25	18	68	7.00		53.2
3:30	1:15	1.00	25	18	68	6.90		52.4
3:45	1:30	1.00	25	18	68	7.00		53.2
4:00	1:45	1.00	25	18	68	7.00		53.2
4:15	2:00	1.00	25	18	68	7.00		53.2
4:30	2:15	1.00	25	18	68	6.90		52.4
4:45	2:30	1.00	25	18	69	6.90		52.4
8:15	18:00	1.00	25	18	69	6.70		50.9
8:45	18:30	1.00	25	18	69	6.70	Started Concentrating	50.9
9:15	19:00	1.00	25	18	69	6.60		50.2
9:45	19:30	1.00	25	18	69	6.50		49.4
10:15	20:00	1.00	25	18	70	6.40		48.6
10:45	20:30	1.00	25	18	69	6.20		47.0
11:15	21:00	1.00	25	18	68	5.90		44.8
11:45	21:30	1.00	25	18	68	5.70		43.3
12:15	22:00	1.00	25	18	67	5.70		43.3
12:45	22:30	1.00	25	18	67	5.60		42.6
1:15	23:00	1.00	25	18	67	5.40		41.0
1:45	23:30	1.00	25	18	67	5.50		41.8
2:15	0:00	1.00	25	18	68	5.40		41.0
2:45	0:30	1.00	25	18	68	5.40		41.0

Table A-4. ST-IIL Rotary Membrane Tests—100,000 Molecular Weight Cut-Off Membrane (ST-II-L Test 1) Raw Data Run Log

Time of Day	Elapsed Time (dd:hh:mm)	Feed Pressure (psi)	Feed Temp. (°F)	Feed Flow (gpm)	Rotor Speed (rpm)	Rotor Power (kW)	Permeate Flow (gph)	Permeate Flux (gal/ft²-day)
15:00	0:00	40	62	1.00	967	967	4.88	117.17
15:10	0:10	39	65	1.00	1195	1195	4.26	102.33
15:15	0:15	39	65	1.01	1190	1190	4.36	104.61
15:20	0:20	40	66	1.01	1183	1183	4.55	109.18
15:25	0:25	40	67	1.01	1191	1191	4.66	111.84
15:30	0:30	40	67	1.01	1184	1184	4.58	109.94
15:35	0:35	40	68	1.01	1187	1187	4.69	112.60
15:40	0:40	40	69	1.01	1188	1188	4.55	109.18
15:45	0:45	40	69	1.02	1181	1181	4.69	112.60
15:50	0:50	40	70	1.02	1188	1188	4.66	111.84
15:55	0:55	40	71	1.01	1180	1180	4.66	111.84
16:00	1:00	39	71	1.02	1188	1188	4.64	111.46
16:05	1:05	40	72	1.02	1182	1182	4.82	115.64
16:10	1:10	40	73	1.02	1185	1185	4.72	113.36
16:15	1:15	39	73	1.03	1190	1190	4.85	116.40
16:20	1:20	39	73	1.03	1186	1186	4.79	114.88
16:25	1:25	40	74	1.03	1170	1170	4.61	110.70
16:35	1:35	40	74	1.03	1188	1188	4.64	111.46
16:50	1:50	40	75	1.02	1189	1189	4.69	112.60
17:05	2:05	40	75	1.03	1187	1187	4.64	111.46
17:20	2:20	39	75	1.02	1186	1186	4.49	107.66
17:35	2:35	40	75	1.03	1186	1186	4.58	109.94
17:50	2:50	40	75	1.02	1184	1184	4.64	111.46
18:05	3:05	40	74	1.02	1183	1183	4.55	109.18
18:20	3:20	39	74	1.03	1184	1184	4.61	110.70
18:35	3:35	40	74	1.02	1185	1185	4.39	105.37
18:50	3:50	39	74	1.01	1183	1183	4.49	107.66
19:05	4:05	39	75	1.02	1178	1178	4.49	107.66
19:20	4:20	40	75	1.02	1186	1186	4.39	105.37
19:35	4:35	39	75	1.02	1186	1186	4.36	104.61
19:50	4:50	40	75	1.03	1186	1186	4.45	106.89
20:05	5:05	40	75	1.01	1188	1188	4.42	106.13
20:20	5:20	40	75	1.02	1175	1175	4.23	101.57
20:35	5:35	40	75	1.03	1177	1177	4.39	105.37
20:50	5:50	40	74	1.02	1182	1182	4.23	101.57

Table A-4. (continued).

Time of Day	Elapsed Time (dd:hh:mm)	Feed Pressure (psi)	Feed Temp. (°F)	Feed Flow (gpm)	Rotor Speed (rpm)	Rotor Power (kW)	Permeate Flow (gph)	Permeate Flux (gal/ft²-day)
21:05	6:05	39	74	1.02	1181	1181	4.23	101.57
21:20	6:20	40	75	1.02	1179	1179	4.33	103.85
21:35	6:35	39	74	1.03	1195	1195	4.30	103.09
21:50	6:50	39	74	1.03	1181	1181	4.26	102.33
22:05	7:05	40	75	1.02	1179	1179	4.20	100.81
22:20	7:20	40	74	1.03	1186	1186	4.26	102.33
22:35	7:35	39	74	1.03	1185	1185	4.20	100.81
22:50	7:50	40	74	1.02	1180	1180	4.17	100.05
23:05	8:05	40	74	1.02	1180	1180	4.07	97.76
23:20	8:20	40	74	1.02	1179	1179	4.11	98.53
23:35	8:35	39	74	1.03	1181	1181	4.07	97.76
23:50	8:50	40	74	1.02	1185	1185	4.11	98.53
0:00	8:59	39	74	1.03	1194	1194	4.11	98.53
0:15	9:14	40	74	1.03	1178	1178	4.07	97.76
0:30	9:29	40	74	1.02	1188	1188	4.01	96.24
0:45	9:44	39	74	1.02	1188	1188	4.04	97.00
1:00	9:59	39	74	1.02	1186	1186	3.96	95.10
1:15	10:14	39	74	1.03	1181	1181	4.01	96.24
1:30	10:29	40	74	1.02	1191	1191	3.96	95.10
1:45	10:44	39	74	1.02	1173	1173	4.01	96.24
2:00	10:59	39	74	1.03	1181	1181	3.93	94.34
2:15	11:14	39	74	1.03	1185	1185	3.96	95.10
2:30	11:29	40	74	1.03	1181	1181	3.96	95.10
2:45	11:44	40	74	1.03	1186	1186	3.93	94.34
3:00	11:59	39	74	1.03	1181	1181	3.87	92.82
3:15	12:14	39	74	1.02	1174	1174	3.90	93.58
3:30	12:29	40	74	1.03	1180	1180	3.93	94.34
3:45	12:44	39	74	1.03	1184	1184	3.96	95.10
4:00	12:59	40	74	1.03	1185	1185	3.84	92.06
4:15	13:14	40	74	1.03	1182	1182	3.90	93.58
4:30	13:29	39	74	1.03	1182	1182	3.77	90.54
4:45	13:44	40	73	1.03	1181	1181	3.80	91.30
5:00	13:59	39	74	1.03	1187	1187	3.87	92.82
5:15	14:14	40	74	1.03	1176	1176	3.77	90.54
5:30	14:29	39	74	1.03	1181	1181	3.80	91.30
5:45	14:44	40	73	1.03	1181	1181	3.80	91.30

Table A-4. (continued).

Time of Day	Elapsed Time (dd:hh:mm)	Feed Pressure (psi)	Feed Temp. (°F)	Feed Flow (gpm)	Rotor Speed (rpm)	Rotor Power (kW)	Permeate Flow (gph)	Permeate Flux (gal/ft²-day)
6:00	14:59	39	74	1.03	1184	1184	3.74	89.78
6:15	15:14	40	73	1.03	1190	1190	3.77	90.54
6:30	15:29	40	73	1.03	1184	1184	3.71	89.02
6:45	15:44	40	74	1.03	1182	1182	3.77	90.54
7:00	15:59	39	74	1.03	1177	1177	3.74	89.78
7:15	16:14	40	74	1.03	1177	1177	3.74	89.78
7:30	16:29	40	73	1.04	1188	1188	3.77	90.54
7:45	16:44	39	73	1.03	1188	1188	3.77	90.54
8:00	16:59	40	73	1.03	1187	1187	3.77	90.54
8:15	17:14	40	73	1.03	1189	1189	3.74	89.78
8:30	17:29	39	73	1.03	1184	1184	3.74	89.78
8:45	17:44	40	73	1.03	1181	1181	3.71	89.02
9:00	17:59	39	73	1.03	1182	1182	3.74	89.78
9:15	18:14	40	73	1.02	1183	1183	3.71	89.02

Table A-5. ST-IIL Rotary Membrane Tests—100,000 Molecular Weight Cut-Off Membrane (ST-II-L Test 1) Concentration Data Run Log

Time of Day	Elapsed Time (dd:hh:mm)	Feed Pressure (psi)	Feed Temp. (°F)	Feed Flow (gpm)	Rotor Speed (rpm)	Rotor Power (kW)	Permeate Flow (gph)	Permeate Flux (gal/ft²-day)
9:30	18:29	40	73	1.02	1182	1182	3.71	89.02
9:45	18:44	39	73	1.03	1188	1188	3.71	89.02
10:00	18:59	40	73	1.03	1179	1179	3.68	88.25
10:15	19:14	39	73	1.03	1187	1187	3.61	86.73
10:30	19:29	39	73	1.03	1192	1192	3.65	87.49
10:45	19:44	39	73	1.03	1172	1172	3.61	86.73
11:00	19:59	39	73	1.02	1180	1180	3.55	85.21
11:15	20:14	39	73	1.03	1183	1183	3.55	85.21
11:30	20:29	39	73	1.03	1185	1185	3.61	86.73
11:45	20:44	39	72	1.03	1180	1180	3.52	84.45
12:00	20:59	40	73	1.02	1181	1181	3.58	85.97
12:15	21:14	40	72	1.03	1174	1174	3.58	85.97
12:30	21:29	39	72	1.02	1181	1181	3.58	85.97
12:45	21:44	39	73	1.03	1177	1177	3.55	85.21
13:00	21:59	39	72	1.03	1181	1181	3.55	85.21
13:15	22:14	40	72	1.03	1168	1168	3.49	83.69
13:30	22:29	40	72	1.03	1190	1190	3.49	83.69
13:45	22:44	40	73	1.03	1189	1189	3.49	83.69
14:00	22:59	40	73	1.03	1183	1183	3.46	82.93
14:15	23:14	40	74	1.03	1181	1181	3.36	80.65
14:30	23:29	39	73	1.03	1186	1186	3.31	79.51
14:45	23:44	40	73	1.03	1182	1182	3.22	77.22
15:00	23:59	40	73	1.03	1187	1187	3.09	74.18
15:15	0:14	40	73	1.03	1177	1177	3.09	74.18
15:30	0:29	39	73	1.02	1182	1182	3.06	73.42

Table A-6. ST-IIL Rotary Membrane Tests—100,000 Molecular Weight Cut-Off Membrane (ST-II-L Test 2) Raw Data Run Log

Time of Day	Elapsed Time (dd:hh:hm)	Feed Pressure (psi)	Feed Temp. (°F)	Feed Flow (gpm)	Rotor Speed (rpm)	Rotor Power (kW)	Permeate Flow (gph)	Permeate Flux (gal/ft²-day)
15:09	0:00	41	69	1.03	1185	1185	3.09	74.18
15:24	0:15	40	71	1.01	1201	1201	3.15	75.70
15:39	0:30	39	73	1.01	1200	1200	3.36	80.65
15:54	0:45	39	74	1.01	1197	1197	3.42	82.17
16:09	1:00	40	75	1.01	1206	1206	3.39	81.41
16:24	1:15	40	76	1.00	1198	1198	3.49	83.69
16:39	1:30	39	76	1.01	1196	1196	3.52	84.45
16:54	1:45	40	77	1.00	1199	1199	3.68	88.25
17:09	2:00	40	77	1.00	1198	1198	3.61	86.73
17:24	2:15	40	77	1.00	1198	1198	3.68	88.25
17:39	2:30	39	77	1.00	1195	1195	3.65	87.49
17:54	2:45	39	78	1.01	1200	1200	3.68	88.25
18:09	3:00	40	78	1.00	1200	1200	3.74	89.78
18:24	3:15	39	78	1.00	1207	1207	3.71	89.02
18:39	3:30	40	78	1.00	1200	1200	3.68	88.25
18:54	3:45	39	78	1.01	1201	1201	3.71	89.02
19:09	4:00	40	78	1.01	1205	1205	3.84	92.06
19:24	4:15	39	78	1.00	1198	1198	3.77	90.54
19:39	4:30	40	78	1.00	1195	1195	3.80	91.30
19:54	4:45	40	78	1.00	1195	1195	3.84	92.06
20:09	5:00	40	78	1.00	1200	1200	3.84	92.06
20:24	5:15	39	78	0.98	1203	1203	3.77	90.54
20:39	5:30	40	78	0.99	1198	1198	3.80	91.30
20:54	5:45	40	78	1.00	1195	1195	3.87	92.82
21:09	6:00	39	78	1.00	1195	1195	3.87	92.82
21:24	6:15	39	78	1.00	1204	1204	3.84	92.06
21:39	6:30	40	78	1.00	1195	1195	3.84	92.06
21:54	6:45	39	78	1.00	1197	1197	3.93	94.34
22:09	7:00	39	78	0.99	1198	1198	3.84	92.06
22:24	7:15	39	78	1.00	1208	1208	3.87	92.82
22:39	7:30	40	78	1.00	1199	1199	3.87	92.82
22:54	7:45	40	78	1.00	1198	1198	3.87	92.82
23:09	8:00	39	78	1.01	1197	1197	3.87	92.82
23:24	8:15	40	78	1.00	1199	1199	3.90	93.58
23:39	8:30	39	78	0.99	1198	1198	3.90	93.58

Table A-6. (continued).

Time of Day	Elapsed Time (dd:hh:hm)	Feed Pressure (psi)	Feed Temp. (°F)	Feed Flow (gpm)	Rotor Speed (rpm)	Rotor Power (kW)	Permeate Flow (gph)	Permeate Flux (gal/ft²-day)
23:54	8:45	40	78	1.00	1202	1202	3.80	91.30
0:00	8:50	39	78	1.00	1201	1201	3.84	92.06
0:15	9:05	40	78	1.01	1201	1201	3.87	92.82
0:30	9:20	40	78	1.00	1195	1195	3.87	92.82
0:45	9:35	40	78	1.00	1199	1199	3.84	92.06
1:00	9:50	40	78	1.00	1199	1199	3.90	93.58
1:15	10:05	39	78	1.00	1202	1202	3.90	93.58
1:30	10:20	40	78	1.00	1198	1198	3.96	95.10
1:45	10:35	40	79	1.00	1209	1209	3.87	92.82
2:00	10:50	39	79	1.00	1197	1197	3.87	92.82
2:15	11:05	40	78	1.00	1197	1197	3.93	94.34
2:30	11:20	40	78	1.00	1202	1202	3.87	92.82
2:45	11:35	39	78	1.00	1195	1195	3.90	93.58
3:00	11:50	40	79	1.00	1202	1202	3.90	93.58
3:15	12:05	39	78	0.99	1195	1195	3.90	93.58
3:30	12:20	40	78	1.00	1196	1196	3.87	92.82
3:45	12:35	40	79	1.00	1205	1205	3.90	93.58
4:00	12:50	40	79	1.00	1195	1195	3.90	93.58
4:15	13:05	40	79	1.00	1202	1202	3.87	92.82
4:30	13:20	40	79	1.01	1199	1199	3.87	92.82
4:45	13:35	40	79	1.00	1195	1195	3.93	94.34
5:00	13:50	40	78	1.00	1197	1197	3.87	92.82
5:15	14:05	39	79	1.00	1201	1201	3.93	94.34
5:30	14:20	39	78	1.00	1200	1200	3.90	93.58
5:45	14:35	39	78	1.00	1204	1204	3.90	93.58
6:00	14:50	40	79	1.00	1200	1200	3.99	95.86
6:15	15:05	39	79	1.00	1206	1206	3.77	90.54
6:30	15:20	39	79	1.00	1201	1201	3.80	91.30
6:45	15:35	39	79	1.00	1206	1206	3.87	92.82
7:00	15:50	40	79	1.00	1197	1197	3.87	92.82
7:15	16:05	39	79	1.01	1207	1207	3.90	93.58
7:30	16:20	40	79	1.00	1200	1200	3.87	92.82
7:45	16:35	40	79	1.00	1198	1198	3.93	94.34
8:00	16:50	39	79	1.00	1197	1197	3.84	92.06
8:15	17:05	39	79	1.00	1202	1202	3.99	95.86
8:30	17:20	39	79	1.00	1198	1198	3.80	91.30

Table A-6. (continued).

Time of Day	Elapsed Time (dd:hh:hm)	Feed Pressure (psi)	Feed Temp. (°F)	Feed Flow (gpm)	Rotor Speed (rpm)	Rotor Power (kW)	Permeate Flow (gph)	Permeate Flux (gal/ft²-day)
8:45	17:35	39	79	1.00	1198	1198	3.84	92.06
9:00	17:50	39	79	1.00	1199	1199	3.93	94.34
9:15	18:05	39	78	1.00	1200	1200	3.87	92.82
9:30	18:20	40	78	1.00	1198	1198	3.87	92.82
9:45	18:35	40	77	1.00	1199	1199	3.84	92.06
10:00	18:50	39	77	1.00	1197	1197	3.87	92.82
10:15	19:05	40	77	1.00	1196	1196	3.84	92.06
10:30	19:20	39	77	1.01	1199	1199	3.84	92.06
10:45	19:35	39	77	1.00	1203	1203	3.87	92.82
11:00	19:50	40	77	1.00	1198	1198	3.90	93.58
11:15	20:05	39	77	1.00	1197	1197	3.84	92.06
11:30	20:20	39	77	1.00	1206	1206	3.80	91.30
11:45	20:35	40	77	1.01	1198	1198	3.87	92.82
12:00	20:50	39	77	1.00	1196	1196	3.84	92.06
12:15	21:05	39	77	1.00	1198	1198	3.90	93.58
12:30	21:20	39	77	1.00	1197	1197	3.84	92.06
12:45	21:35	40	77	1.00	1199	1199	3.87	92.82
13:00	21:50	39	77	0.99	1198	1198	3.87	92.82
13:15	22:05	40	78	1.00	1199	1199	3.90	93.58
13:30	22:20	39	78	1.00	1197	1197	3.84	92.06
13:45	22:35	39	78	1.00	1196	1196	3.87	92.82
14:00	22:50	40	78	1.00	1196	1196	3.84	92.06
14:15	23:05	39	79	1.00	1202	1202	3.90	93.58
14:30	23:20	40	78	1.00	1194	1194	3.87	92.82
14:45	23:35	39	78	1.00	1197	1197	3.87	92.82
15:00	23:50	39	79	1.00	1196	1196	3.77	90.54
15:15	0:05	39	78	1.00	1194	1194	3.77	90.54
15:30	0:20	40	78	1.00	1195	1195	3.80	91.30
15:45	0:35	39	78	1.01	1195	1195	3.77	90.54
16:00	0:50	40	77	1.00	1195	1195	3.77	90.54
16:15	1:05	39	77	1.00	1196	1196	3.77	90.54
16:30	1:20	40	77	1.03	1199	1199	3.55	85.21
16:45	1:35	40	78	1.03	1201	1201	3.52	84.45
17:00	1:50	40	78	1.02	1192	1192	3.49	83.69
17:15	2:05	40	77	1.03	1197	1197	3.52	84.45
17:30	2:20	40	78	1.02	1198	1198	3.49	83.69
17:45	2:35	40	77	1.03	1195	1195	3.52	84.45

Table A-7. ST-IIL Rotary Membrane Tests—100,000 Molecular Weight Cut-Off Membrane (ST-II-L Test 2) Concentration Data Run Log.

Time of Day	Elapsed Time (dd:hh:mm)	Feed Pressure (psi)	Feed Temp (°F)	Feed Flow (gpm)	Rotor Speed (rpm)	Rotor Power (kW)	Permeate Flow (gph)	Permeate Flux (gal/ft²-day)
16:45	1:35	40	78	1.03	1201	1201	3.52	84.45
17:00	1:50	40	78	1.02	1192	1192	3.49	83.69
17:15	2:05	40	77	1.03	1197	1197	3.52	84.45
17:30	2:20	40	78	1.02	1198	1198	3.49	83.69
17:45	2:35	40	77	1.03	1195	1195	3.52	84.45
18:00	2:50	40	77	1.02	1193	1193	3.52	84.45
18:15	3:05	38	77	1.03	1208	1208	3.49	83.69
18:30	3:20	39	78	1.02	1198	1198	3.55	85.21
18:45	3:35	40	77	1.03	1199	1199	3.52	84.45
19:00	3:50	40	77	1.01	1202	1202	3.46	82.93
19:15	4:05	40	77	1.01	1197	1197	3.55	85.21
19:30	4:20	39	77	1.02	1196	1196	3.49	83.69
19:45	4:35	40	77	1.02	1198	1198	3.52	84.45
20:00	4:50	40	77	1.02	1195	1195	3.52	84.45
20:15	5:05	40	77	1.02	1197	1197	3.49	83.69
20:30	5:20	39	77	1.02	1195	1195	3.49	83.69
20:45	5:35	39	77	1.03	1205	1205	3.46	82.93
21:00	5:50	40	77	1.03	1195	1195	3.49	83.69
21:15	6:05	39	77	1.02	1197	1197	3.49	83.69
21:30	6:20	39	77	1.03	1197	1197	3.52	84.45
21:45	6:35	40	77	1.02	1204	1204	3.55	85.21
22:00	6:50	39	77	1.02	1198	1198	3.49	83.69
22:15	7:05	40	77	1.02	1195	1195	3.49	83.69
22:30	7:20	40	77	1.02	1201	1201	3.49	83.69
22:45	7:35	39	77	1.03	1196	1196	3.49	83.69
23:00	7:50	40	77	1.02	1199	1199	3.49	83.69
23:15	8:05	40	77	1.02	1205	1205	3.52	84.45
23:30	8:20	39	77	1.02	1194	1194	3.52	84.45
23:45	8:35	39	77	1.02	1201	1201	3.49	83.69
0:00	8:50	40	77	1.03	1198	1198	3.52	84.45
0:15	9:05	40	77	1.03	1196	1196	3.52	84.45
0:30	9:20	39	77	1.03	1196	1196	3.52	84.45
0:45	9:35	39	77	1.03	1199	1199	3.49	83.69
1:00	9:50	40	77	1.02	1199	1199	3.46	82.93
1:15	10:05	39	77	1.02	1203	1203	3.46	82.93

Table 7. (continued).

Time of Day	Elapsed Time (dd:hh:mm)	Feed Pressure (psi)	Feed Temp (°F)	Feed Flow (gpm)	Rotor Speed (rpm)	Rotor Power (kW)	Permeate Flow (gph)	Permeate Flux (gal/ft²-day)
1:30	10:20	40	78	1.03	1198	1198	3.42	82.17
1:45	10:35	39	77	1.03	1200	1200	3.46	82.93
2:00	10:50	39	77	1.03	1196	1196	3.46	82.93
2:15	11:05	39	77	1.03	1202	1202	3.46	82.93
2:30	11:20	40	77	1.03	1195	1195	3.46	82.93
2:45	11:35	40	77	1.03	1199	1199	3.46	82.93
3:00	11:50	39	77	1.02	1199	1199	3.46	82.93
3:15	12:05	39	77	1.03	1198	1198	3.39	81.41
3:30	12:20	39	77	1.03	1197	1197	3.39	81.41
3:45	12:35	39	77	1.03	1201	1201	3.39	81.41
4:00	12:50	40	77	1.03	1200	1200	3.42	82.17
4:15	13:05	40	77	1.03	1199	1199	3.39	81.41
4:30	13:20	39	76	1.03	1206	1206	3.39	81.41
4:45	13:35	39	76	1.03	1199	1199	3.36	80.65
5:00	13:50	40	77	1.03	1205	1205	3.36	80.65
5:15	14:05	39	77	1.03	1198	1198	3.39	81.41
5:30	14:20	40	77	1.03	1201	1201	3.39	81.41
5:45	14:35	40	77	1.03	1198	1198	3.36	80.65
6:00	14:50	39	76	1.03	1201	1201	3.33	79.89
6:15	15:05	39	76	1.03	1197	1197	3.31	79.51
6:30	15:20	40	76	1.03	1202	1202	3.33	79.89
6:45	15:35	39	76	1.02	1200	1200	3.33	79.89
7:00	15:50	40	76	1.03	1197	1197	3.36	80.65
7:15	16:05	40	76	1.03	1200	1200	3.39	81.41
7:30	16:20	40	76	1.03	1199	1199	3.31	79.51
7:45	16:35	39	76	1.03	1197	1197	3.36	80.65
8:00	16:50	39	76	1.03	1199	1199	3.33	79.89
8:15	17:05	40	77	1.03	1201	1201	3.39	81.41
8:30	17:20	40	78	1.03	1203	1203	3.46	82.93
8:45	17:35	40	79	1.02	1207	1207	3.39	81.41
9:00	17:50	39	79	1.03	1197	1197	3.39	81.41
9:15	18:05	40	79	1.03	1203	1203	3.33	79.89
9:30	18:20	39	79	1.03	1199	1199	3.31	79.51
9:45	18:35	40	79	1.03	1199	1199	3.36	80.65
10:00	18:50	40	80	1.03	1199	1199	3.19	76.46
10:15	19:05	40	80	1.03	1203	1203	3.25	77.98

Table 7. (continued).

Time of Day	Elapsed Time (dd:hh:mm)	Feed Pressure (psi)	Feed Temp (°F)	Feed Flow (gpm)	Rotor Speed (rpm)	Rotor Power (kW)	Permeate Flow (gph)	Permeate Flux (gal/ft²-day)
10:30	19:20	39	80	1.02	1204	1204	3.25	77.98
10:45	19:35	39	79	1.03	1200	1200	3.25	77.98
11:00	19:50	40	80	1.04	1200	1200	3.15	75.70
11:15	20:05	39	80	1.03	1198	1198	3.15	75.70
11:30	20:20	40	79	1.03	1196	1196	3.09	74.18
11:45	20:35	40	79	1.03	1197	1197	3.06	73.42
12:00	20:50	40	80	1.02	1206	1206	3.06	73.42
12:15	21:05	40	79	1.03	1201	1201	2.93	70.38
12:30	21:20	40	79	1.02	1196	1196	2.90	69.61
12:45	21:35	40	80	1.03	1203	1203	2.84	68.09
13:00	21:50	40	80	1.03	1205	1205	2.77	66.57
13:15	22:05	40	79	1.03	1194	1194	2.66	63.91
13:30	22:20	40	80	1.03	1195	1195	2.60	62.39
13:45	22:35	40	80	1.03	1200	1200	2.50	60.10
14:00	22:50	40	80	1.02	1199	1199	2.38	57.06
14:15	23:05	40	80	1.03	1195	1195	2.22	53.26
14:30	23:20	39	80	1.03	1196	1196	2.09	50.21
14:45	23:35	40	80	1.03	1197	1197	1.98	47.55
15:00	23:50	40	79	1.03	1196	1196	1.76	42.23

Table A-8. ST-IIL Rotary Membrane Tests—10,000 Molecular Weight Cut-Off Membrane (ST-II-l 10K Tests 3) Raw Data Run Log.

Time of Day	Elapsed Time (dd:hh:mm)	Feed Pressure (psi)	Feed Temp. (°F)	Feed Flow (gpm)	Rotor Speed (rpm)	Rotor Power (kW)	Permeate Flow (gph)	Permeate Flux (gal/ft²-day)
9:41	0:00	41	71	1.03	648	648	3.22	77.22
9:56	0:15	39	72	1.03	640	640	2.57	61.63
10:11	0:30	40	72	1.03	639	639	2.60	62.39
10:26	0:45	40	73	1.03	1203	1203	2.66	63.91
10:41	1:00	39	76	1.03	1203	1203	2.81	67.33
10:56	1:15	40	77	1.03	1201	1201	2.96	71.14
11:11	1:30	40	78	1.03	1209	1209	3.06	73.42
11:26	1:45	40	79	1.03	1201	1201	3.06	73.42
11:41	2:00	40	80	1.03	1202	1202	3.09	74.18
11:56	2:15	39	81	1.03	1196	1196	3.25	77.98
12:11	2:30	39	82	1.03	1201	1201	3.19	76.46
12:26	2:45	39	82	1.03	1194	1194	3.15	75.70
12:41	3:00	40	83	1.03	1192	1192	3.15	75.70
12:56	3:15	39	83	1.02	1194	1194	3.15	75.70
13:11	3:30	40	84	1.02	1197	1197	3.19	76.46
13:26	3:45	40	84	1.03	1195	1195	3.33	79.89
13:41	4:00	39	84	1.03	1179	1179	3.22	77.22
13:56	4:15	39	84	1.02	1197	1197	3.19	76.46
14:11	4:30	39	85	1.03	1197	1197	3.28	78.74
14:26	4:45	40	85	1.03	1204	1204	3.28	78.74
14:41	5:00	39	85	1.03	1190	1190	3.22	77.22
14:56	5:15	40	86	1.02	1185	1185	3.31	79.51
15:11	5:30	40	86	1.03	1197	1197	3.31	79.51
15:26	5:45	40	86	1.02	1191	1191	3.42	82.17
15:41	6:00	39	86	1.02	1193	1193	3.49	83.69
15:56	6:15	39	86	1.03	1196	1196	3.22	77.22
16:11	6:30	39	87	1.02	1198	1198	3.36	80.65
16:26	6:45	40	87	1.03	1198	1198	3.42	82.17
16:41	7:00	40	86	1.03	1196	1196	3.22	77.22
16:56	7:15	40	86	1.02	1195	1195	3.31	79.51
17:11	7:30	39	86	1.02	1192	1192	3.36	80.65
17:26	7:45	39	87	1.02	1195	1195	3.46	82.93
17:41	8:00	40	86	1.02	1197	1197	3.39	81.41
17:56	8:15	40	87	1.02	1188	1188	3.36	80.65
18:11	8:30	40	87	1.03	1190	1190	3.31	79.51

Table A-8. (continued).

Time of Day	Elapsed Time (dd:hh:mm)	Feed Pressure (psi)	Feed Temp. (°F)	Feed Flow (gpm)	Rotor Speed (rpm)	Rotor Power (kW)	Permeate Flow (gph)	Permeate Flux (gal/ft²-day)
18:26	8:45	39	87	1.03	1197	1197	3.31	79.51
18:41	9:00	40	87	1.03	1194	1194	3.39	81.41
18:56	9:15	40	88	1.02	1201	1201	3.22	77.22
19:11	9:30	40	87	1.03	1197	1197	3.31	79.51
19:26	9:45	40	87	1.03	1202	1202	3.31	79.51
19:41	10:00	40	86	1.03	1199	1199	3.28	78.74
19:56	10:15	40	86	1.02	1194	1194	3.33	79.89
20:11	10:30	39	87	1.02	1206	1206	3.36	80.65
20:26	10:45	40	86	1.02	1197	1197	3.46	82.93
20:41	11:00	40	87	1.03	1195	1195	3.36	80.65
20:56	11:15	39	87	1.02	1202	1202	3.25	77.98
21:11	11:30	39	87	1.02	1191	1191	3.39	81.41
21:26	11:45	39	87	1.02	1198	1198	3.39	81.41
21:41	12:00	39	87	1.02	1189	1189	3.33	79.89
21:56	12:15	40	87	1.02	1188	1188	3.46	82.93
22:11	12:30	39	87	1.02	1192	1192	3.15	75.70
22:26	12:45	40	87	1.02	1199	1199	3.33	79.89
22:41	13:00	40	87	1.03	1196	1196	3.25	77.98
22:56	13:15	39	86	1.02	1194	1194	3.19	76.46
23:11	13:30	39	87	1.03	1195	1195	3.15	75.70
23:26	13:45	40	86	1.02	1196	1196	3.33	79.89
23:41	14:00	39	86	1.02	1195	1195	3.25	77.98
23:56	14:15	40	86	1.03	1198	1198	3.19	76.46
0:00	14:18	39	87	1.03	1196	1196	3.39	81.41
0:15	14:33	39	86	1.02	1195	1195	3.31	79.51
0:30	14:48	39	87	1.02	1198	1198	3.12	74.94
0:45	15:03	40	87	1.02	1190	1190	3.46	82.93
1:00	15:18	40	87	1.02	1203	1203	3.22	77.22
1:15	15:33	40	87	1.03	1191	1191	3.19	76.46
1:30	15:48	40	86	1.03	1196	1196	3.09	74.18
1:45	16:03	40	86	1.03	1193	1193	3.33	79.89
2:00	16:18	40	87	1.03	1196	1196	3.33	79.89
2:15	16:33	40	86	1.02	1192	1192	3.22	77.22
2:30	16:48	40	87	1.03	1189	1189	3.09	74.18
2:45	17:03	40	86	1.02	1194	1194	3.25	77.98
3:00	17:18	40	86	1.03	1195	1195	3.19	76.46

Table A-8. (continued).

Time of Day	Elapsed Time (dd:hh:mm)	Feed Pressure (psi)	Feed Temp. (°F)	Feed Flow (gpm)	Rotor Speed (rpm)	Rotor Power (kW)	Permeate Flow (gph)	Permeate Flux (gal/ft²-day)
3:15	17:33	40	86	1.02	1195	1195	3.31	79.51
3:30	17:48	39	87	1.02	1192	1192	3.19	76.46
3:45	18:03	39	87	1.02	1195	1195	3.15	75.70
4:00	18:18	39	86	1.02	1198	1198	3.15	75.70
4:15	18:33	39	86	1.02	1198	1198	3.31	79.51
4:30	18:48	39	86	1.03	1188	1188	3.31	79.51
4:45	19:03	40	86	1.02	1193	1193	3.06	73.42
5:00	19:18	40	86	1.02	1199	1199	3.19	76.46
5:15	19:33	40	86	1.02	1187	1187	3.42	82.17
5:30	19:48	39	86	1.02	1198	1198	3.22	77.22
5:45	20:03	40	86	1.02	1195	1195	3.28	78.74
6:00	20:18	40	85	1.03	1196	1196	3.19	76.46
6:15	20:33	39	86	1.01	1197	1197	3.22	77.22
6:30	20:48	40	86	1.01	1194	1194	3.55	85.21
6:45	21:03	40	86	1.01	1196	1196	3.28	78.74
7:00	21:18	39	86	1.00	1195	1195	3.61	86.73
7:15	21:33	40	85	1.00	1195	1195	3.55	85.21
7:30	21:48	40	85	1.00	1200	1200	3.36	80.65
7:45	22:03	40	85	1.00	1200	1200	3.52	84.45
8:00	22:18	40	84	1.00	1202	1202	3.25	77.98
8:15	22:33	40	80	1.01	1195	1195	3.15	75.70

Table A-9. ST-IIL Rotary Membrane Tests—10,000 Molecular Weight Cut-Off Membrane (ST-II-l 10K Tests 3) Concentration Data Run Log.

Time of Day	Elapsed Time (dd:hh:mm)	Feed Pressure (psi)	Feed Temp (°F)	Feed Flow (gpm)	Rotor Speed (rpm)	Rotor Power (kW)	Permeate Flow (gph)	Permeate Flux (gal/ft²-day)
8:30	22:48	39	81	1.01	1202	1202	2.71	65.05
8:45	23:03	39	82	1.02	1196	1196	2.68	64.29
9:00	23:18	40	82	1.02	1197	1197	2.68	64.29
9:15	23:33	39	82	1.02	1200	1200	2.63	63.15
9:30	23:48	40	83	1.02	1198	1198	2.71	65.05
9:45	0:03	39	84	1.02	1198	1198	2.74	65.81
10:00	0:18	40	84	1.02	1195	1195	2.68	64.29
10:15	0:33	39	85	1.02	1200	1200	2.68	64.29
10:30	0:48	40	86	1.02	1194	1194	2.71	65.05
10:45	1:03	40	86	1.01	1197	1197	2.90	69.61
11:00	1:18	40	87	1.02	1199	1199	2.74	65.81
11:15	1:33	39	86	1.03	1190	1190	2.77	66.57
11:30	1:48	39	86	1.02	1194	1194	2.71	65.05
11:45	2:03	39	86	1.03	1197	1197	2.90	69.61
12:00	2:18	40	86	1.02	1198	1198	2.77	66.57
12:15	2:33	39	87	1.02	1197	1197	2.71	65.05
12:30	2:48	40	86	1.02	1195	1195	2.87	68.85
12:45	3:03	39	87	1.03	1190	1190	3.00	71.90
13:00	3:18	39	87	1.02	1201	1201	2.54	60.87
13:15	3:33	40	87	1.02	1198	1198	2.71	65.05
13:30	3:48	39	86	1.01	1203	1203	2.68	64.29
13:45	4:03	40	86	1.02	1196	1196	2.71	65.05
14:00	4:18	40	86	1.01	1198	1198	2.71	65.05
14:15	4:33	39	86	1.02	1193	1193	2.74	65.81
14:30	4:48	40	87	1.02	1195	1195	2.50	60.10
14:45	5:03	40	86	1.03	1192	1192	2.57	61.63
15:00	5:18	40	86	1.02	1200	1200	2.54	60.87
15:15	5:33	39	87	1.02	1195	1195	2.47	59.34
15:30	5:48	40	86	1.03	1196	1196	2.57	61.63
15:45	6:03	39	86	1.03	1194	1194	2.60	62.39
16:00	6:18	39	86	1.03	1198	1198	2.63	63.15
16:15	6:33	39	86	1.01	1193	1193	2.57	61.63
16:30	6:48	39	86	1.02	1193	1193	2.57	61.63
16:45	7:03	40	87	1.03	1192	1192	2.35	56.30
17:00	7:18	39	86	1.02	1196	1196	2.41	57.82

Table A-9. (continued).

Time of Day	Elapsed Time (dd:hh:mm)	Feed Pressure (psi)	Feed Temp (°F)	Feed Flow (gpm)	Rotor Speed (rpm)	Rotor Power (kW)	Permeate Flow (gph)	Permeate Flux (gal/ft²-day)
17:15	7:33	40	86	1.01	1195	1195	2.44	58.58
17:30	7:48	39	85	1.03	1189	1189	2.44	58.58
17:45	8:03	39	85	1.02	1196	1196	2.41	57.82
18:00	8:18	40	85	1.03	1196	1196	2.47	59.34
18:15	8:33	39	85	1.02	1194	1194	2.41	57.82
18:30	8:48	39	85	1.02	1197	1197	2.44	58.58
18:45	9:03	40	85	1.03	1192	1192	2.41	57.82
19:00	9:18	40	85	1.03	1195	1195	2.41	57.82
19:15	9:33	40	85	1.02	1188	1188	2.41	57.82
19:30	9:48	40	85	1.02	1188	1188	2.38	57.06
19:45	10:03	40	84	1.02	1199	1199	2.38	57.06
20:00	10:18	39	85	1.02	1192	1192	2.41	57.82
20:15	10:33	40	84	1.03	1195	1195	2.47	59.34
20:30	10:48	39	85	1.02	1202	1202	2.38	57.06
20:45	11:03	40	85	1.03	1198	1198	2.41	57.82
21:00	11:18	40	84	1.02	1203	1203	2.41	57.82
21:15	11:33	40	85	1.03	1202	1202	2.47	59.34
21:30	11:48	39	84	1.02	1197	1197	2.50	60.10
21:45	12:03	39	84	1.02	1197	1197	2.47	59.34
22:00	12:18	39	84	1.02	1195	1195	2.63	63.15
22:15	12:33	40	84	1.02	1192	1192	2.66	63.91
22:30	12:48	40	84	1.03	1196	1196	2.22	53.26
22:45	13:03	39	85	1.02	1197	1197	2.38	57.06
23:00	13:18	39	85	1.03	1194	1194	2.35	56.30
23:15	13:33	39	85	1.02	1202	1202	2.31	55.54
23:30	13:48	40	85	1.03	1201	1201	2.41	57.82
23:45	14:03	40	84	1.02	1198	1198	2.38	57.06
0:00	14:18	39	84	1.03	1198	1198	2.28	54.78
0:15	14:33	39	85	1.02	1197	1197	2.38	57.06
0:30	14:48	39	85	1.03	1189	1189	2.38	57.06
0:45	15:03	39	85	1.02	1198	1198	2.35	56.30
1:00	15:18	39	84	1.02	1195	1195	2.38	57.06
1:15	15:33	39	84	1.03	1195	1195	2.35	56.30
1:30	15:48	40	84	1.03	1188	1188	2.28	54.78
1:45	16:03	39	84	1.03	1204	1204	2.44	58.58
2:00	16:18	41	84	1.02	1195	1195	2.41	57.82

Table A-9. (continued).

Time of Day	Elapsed Time (dd:hh:mm)	Feed Pressure (psi)	Feed Temp (°F)	Feed Flow (gpm)	Rotor Speed (rpm)	Rotor Power (kW)	Permeate Flow (gph)	Permeate Flux (gal/ft²-day)
2:15	16:33	40	85	1.02	1196	1196	2.31	55.54
2:30	16:48	40	84	1.02	1199	1199	2.25	54.02
2:45	17:03	40	84	1.03	1195	1195	2.71	65.05
3:00	17:18	40	84	1.02	1193	1193	2.74	65.81
3:15	17:33	40	84	1.03	1193	1193	2.35	56.30
3:30	17:48	39	84	1.02	1204	1204	2.54	60.87
3:45	18:03	40	85	1.02	1196	1196	2.28	54.78
4:00	18:18	40	84	1.02	1196	1196	2.31	55.54
4:15	18:33	40	85	1.02	1196	1196	2.25	54.02
4:30	18:48	39	85	1.03	1194	1194	2.28	54.78
4:45	19:03	40	84	1.02	1196	1196	2.16	51.74
5:00	19:18	40	84	1.03	1199	1199	2.50	60.10
5:15	19:33	40	84	1.03	1202	1202	2.09	50.21
5:30	19:48	40	84	1.02	1192	1192	2.35	56.30
5:45	20:03	39	85	1.02	1195	1195	2.63	63.15
6:00	20:18	40	84	1.02	1195	1195	2.41	57.82
6:15	20:33	39	85	1.03	1197	1197	2.03	48.69
6:30	20:48	40	84	1.03	1187	1187	2.35	56.30
6:45	21:03	39	84	1.03	1198	1198	2.35	56.30
7:00	21:18	39	84	1.03	1196	1196	2.57	61.63
7:15	21:33	40	84	1.02	1199	1199	2.54	60.87
7:30	21:48	39	85	1.02	1198	1198	2.31	55.54
7:45	22:03	40	84	1.02	1197	1197	2.03	48.69
8:00	22:18	39	84	1.03	1197	1197	2.41	57.82
8:15	22:33	39	85	1.02	1199	1199	2.25	54.02
8:30	22:48	39	84	1.02	1199	1199	2.41	57.82
8:45	23:03	39	85	1.02	1196	1196	2.28	54.78
9:00	23:18	39	84	1.02	1197	1197	2.31	55.54
9:15	23:33	39	85	1.02	1193	1193	2.35	56.30
9:30	23:48	39	85	1.02	1197	1197	2.41	57.82
9:45	0:03	39	85	1.02	1197	1197	2.38	57.06
10:00	0:18	39	84	1.03	1191	1191	2.25	54.02
10:15	0:33	40	85	1.02	1196	1196	2.31	55.54
10:30	0:48	39	86	1.02	1196	1196	2.35	56.30
10:45	1:03	39	86	1.02	1196	1196	2.44	58.58
11:00	1:18	40	81	0.00	1196	1196	2.35	56.30

Table A-9. (continued).

Time of Day	Elapsed Time (dd:hh:mm)	Feed Pressure (psi)	Feed Temp (°F)	Feed Flow (gpm)	Rotor Speed (rpm)	Rotor Power (kW)	Permeate Flow (gph)	Permeate Flux (gal/ft²-day)
11:15	1:33	40	80	0.00	1196	1196	2.31	55.54
11:30	1:48	39	86	1.03	1202	1202	2.03	48.69
11:45	2:03	39	86	1.03	1195	1195	2.22	53.26
12:00	2:18	40	86	1.03	1198	1198	2.28	54.78
12:15	2:33	40	86	1.02	1200	1200	2.31	55.54
12:36	2:54	40	86	1.01	1202	1202	2.22	53.26
12:51	3:09	39	87	1.02	1196	1196	2.22	53.26
13:06	3:24	40	86	1.02	1194	1194	2.28	54.78
13:21	3:39	39	86	1.03	1195	1195	2.28	54.78
13:36	3:54	39	87	1.03	1197	1197	2.16	51.74
13:51	4:09	40	85	1.02	1190	1190	2.31	55.54
14:06	4:24	39	86	1.01	1191	1191	2.28	54.78
14:21	4:39	39	86	1.03	1188	1188	2.35	56.30
14:36	4:54	40	86	1.04	1189	1189	2.28	54.78
14:51	5:09	40	87	1.03	1196	1196	2.22	53.26
15:06	5:24	40	87	1.03	1194	1194	2.19	52.50
15:21	5:39	39	86	1.03	1188	1188	2.25	54.02
15:36	5:54	40	86	1.03	1195	1195	2.31	55.54
15:51	6:09	39	86	1.02	1187	1187	2.16	51.74
16:06	6:24	40	87	1.02	1198	1198	2.28	54.78
16:21	6:39	39	87	1.02	1197	1197	2.19	52.50
16:36	6:54	39	86	1.02	1184	1184	2.19	52.50
16:51	7:09	40	87	1.02	1195	1195	2.22	53.26
17:06	7:24	39	87	1.02	1195	1195	2.16	51.74
17:21	7:39	39	86	1.02	1198	1198	2.31	55.54
17:36	7:54	40	86	1.02	1194	1194	2.12	50.97
17:51	8:09	39	87	1.02	1202	1202	2.19	52.50
18:06	8:24	39	86	1.03	1195	1195	2.35	56.30
18:21	8:39	39	88	1.03	1195	1195	2.09	50.21
18:36	8:54	40	87	1.03	1192	1192	2.06	49.45
18:51	9:09	40	86	1.03	1194	1194	2.19	52.50
19:06	9:24	40	86	1.02	1194	1194	2.12	50.97
19:21	9:39	39	86	1.03	1189	1189	2.09	50.21
19:36	9:54	40	86	1.02	1196	1196	2.16	51.74
19:51	10:09	40	86	1.02	1195	1195	2.06	49.45
20:06	10:24	39	86	1.03	1186	1186	2.06	49.45
20:21	10:39	39	86	1.02	1195	1195	1.95	46.79

Table A-9. (continued).

Time of Day	Elapsed Time (dd:hh:mm)	Feed Pressure (psi)	Feed Temp (°F)	Feed Flow (gpm)	Rotor Speed (rpm)	Rotor Power (kW)	Permeate Flow (gph)	Permeate Flux (gal/ft²-day)
20:36	10:54	39	87	1.02	1199	1199	2.00	47.93
20:51	11:09	40	87	1.02	1195	1195	2.03	48.69
21:06	11:24	40	87	1.02	1195	1195	2.03	48.69
21:21	11:39	39	85	1.02	1196	1196	2.00	47.93
21:36	11:54	40	86	1.03	1201	1201	1.98	47.55
21:51	12:09	39	86	1.01	1196	1196	1.89	45.27
22:06	12:24	39	86	1.01	1199	1199	1.82	43.75
22:21	12:39	39	86	1.02	1200	1200	1.89	45.27
22:36	12:54	39	86	1.02	1196	1196	1.73	41.46
22:51	13:09	39	86	1.02	1197	1197	1.73	41.46
23:06	13:24	40	86	1.02	1196	1196	1.73	41.46

Table A-10. STC Five-Day Cleaning Test—Static Nano Raw Data Run Log

Membrane: 0.015 nominal µ
Surface Area: 0.05
Feed Sample: Metaldyne Wastewater
Initial Feed Volume: 5 L
Final Feed Volume: 5 L
Final Concentrate: 1x
Final Flux: ~25 gfd

Operator: Jason Gilmour
Date: 3/9/00

Time of Day (hh:mm)	Elapsed Time (hh:mm)	Feed Flow (gal/min)	Feed Press. (psi)	Conc. Press. (psi)	Feed Temp. (°F)	Permeate Flow (mL/min)	Comments	Flux (gpd/sq ft)
	0:00	1.00	60	47	68	25.00		190.0
	0:15	1.00	60	50	69	20.00		152.0
	0:30	1.00	60	50	69	17.00		129.2
	0:45	1.00	60	50	70	16.00		121.6
	1:00	1.00	60	50	71	14.00		106.4
	2:00	1.00	60	50	71	13.00		98.8
	25:00	1.00	60	50	66	3.90		29.6
	49:00	1.00	60	49	69	4.00		30.4
	74:00	1.00	60	50	68	3.80	Testing Procedure	28.9
	98:00	1.00	60	49	70	3.60	Test Stopped, Started Cleaning Procedure	27.4
	121:00	1.00	60	50	70	3.30		25.1
9:00	0:00	1.00	60	50	66	6.50	Resumed Testing	49.4
9:30	0:30	1.00	60	50	66	5.50		41.8
10:00	1:00	1.00	60	50	67	4.70		35.7
10:30	1:30	1.00	60	50	68	4.20		31.9
11:00	2:00	1.00	60	50	68	3.80		28.9
2:00	5:00	1.00	60	50	72	3.60		27.4

Table A-11. Desal 5-Spiral Wound Module 5-Day Cleaning Test, Raw Data Run Log

Membrane: Desal-5 Spiral Wound NF
Surface Area: 26.9 sq ft
Feed Sample: Metaldyne Wastewater
Initial Feed Volume: 10 gal
Final Feed Volume: 10 gal
Final Concentrate: 1x
Final Flux: 15.5 gpd/sq ft

Operator: Jason Gilmour
Date: 3/9/00

Time of Day (hh:mm)	Elapsed Time (hh:mm)	Feed Flow (gal/min)	Feed Press. (psi)	Conc. Press. (psi)	Feed Temp. (°F)	Permeate Flow (mL/min)	Comments	Flux (gpd/sq ft)
	0:00	4.50	180	175	93	1560.00		22.1
	0:15	4.50	180	175	92	1430.00		20.2
	0:30	4.50	180	175	94	1300.00		18.4
	0:45	4.50	180	175	92	1250.00		17.7
	1:00	4.50	180	175	90	1210.00		17.1
	2:00	4.50	180	175	89	1200.00		17.0
	25:00	4.50	180	175	96	1180.00		16.7
	49:00	4.50	180	175	94	1130.00		16.0
	74:00	4.50	180	175	92	1150.00		16.3
	98:00	4.50	180	175	93	1100.00	Test Stopped, Began Cleaning Procedure	15.6
	121:00	4.50	180	175	92	1090.00		15.4
1:00	0:00	4.50	180	175	90	1190.00	Resumed Testing	16.8
1:30	0:30	4.50	180	175	90	1150.00		16.3
2:00	1:00	4.50	180	175	91	1130.00		16.0
2:30	1:30	4.50	180	175	92	1110.00		15.7
3:00	2:00	4.50	180	175	94	1100.00		15.6
6:00	5:00	4.50	180	175	93	1080.00		15.3

Table A-12. Performance Data For Six Week Recycling Of Die Lube.

Trial No.[a]	Date	Speedy	Time	Elapsed Time (hh:mm)	Temp (°F)	Feed (psi)	Con (psi)	Feed Flow (gpm)	Perm. Flow (gpm)	Flux (gfd)	Perm. Total (gal)	Daily Vol. (gal)	Per. COD	Con. TS	Source	Notes
MB1	8/8/2002	1&2	2:45 PM	0:00	76	57	49	6.9	0.860	124	8691			0.80	INF	
MB1	8/8/2002	1&2	2:50 PM	0:05	76	50	44	7.4	0.775	112					INF	Clean, clear, slightly pink permeate.
MB1	8/8/2002	1&2	3:00 PM	0:15	76	50	44	7.4	0.740	107					INF	
MB1	8/8/2002	1&2	8:45 PM	6:00	96	49	44	7.5	0.675	97					INF	
MB1	8/8/2002	1&2	7:15 AM	16:30	99	48	44	7.6	0.650	94	9371	680	12300	2.67	INF	69% Volume Reduction
MB1	8/9/2002	1&2	9:10 AM	18:25	100	50	45	7.6	0.660	95	9433	0	12300	2.67	WASH INF	Started washdown with soft water
MB1	8/9/2002	1&2	9:50 AM	19:05	100	49	44	7.6	0.660	95	9466				WASH INF	washdown until end of day
MB1	8/9/2002	1&2	11:10 AM	20:25	100	49	44	7.7	0.660	95	9510	77			WASH INF	
MB1	8/9/2002	1&2	12:15 PM	21:40	100	49	44	7.7	0.670	96	9565				WASH INF	
MB1	8/9/2002	1&2	2:45 PM	24:00	100	49	44	7.8	0.680	98	9630	197	7240	2.13	WASH INF	0.656 washdown to tank ratio
MB1	8/9/2002	1&2	2:45 PM	24:00	72	49	41	8.2	0.650	94					FLUSH	
MB1	8/9/2002	1&2	2:55 PM	24:05	72	49	42	8.3	0.880	127					FLUSH	
MB1	8/9/2002	1&2	3:00 PM	24:10	74	50	44	8.2	1.020	147					FLUSH	
MB2	8/9/2002	1&2	3:00 PM	0:00	78	50	45	7.7	0.700	101	9663			0.72	INF	
MB2	8/9/2002	1&2	3:15 PM	0:15	79	49	44	7.7	0.670	96					INF	
MB2	8/9/2002	1&2	8:15 PM	5:15	96	49	44	7.5	0.642	92	9867				INF	
MB2	8/10/2002	1&2	8:00 AM	17:00	103	49	44	7.4	0.646	93	10318	655			INF	
MB2	8/10/2002	1&2	9:00 AM	18:00	103	49	44	7.5	0.643	93	10348		10600	ND	INF	69% Volume Reduction
MB2	8/10/2002	1&2	9:05 AM	18:05	103	49	44	7.5	0.645	93	10355	0			WASH INF	
MB2	8/10/2002	1&2	11:30 AM	19:00	103	49	44	7.5	0.670	96	10460	52.5			WASH INF	
MB2	8/10/2002	1&2	2:30 PM	22:00	104	49	44	7.2	0.670	96		160	3900		WASH INF	1.07 washdown

Table A-12. (continued).

Trial No.[a]	Date	Speedy	Time	Elapsed Time (hh:mm)	Temp (°F)	Feed (psi)	Con (psi)	Feed Flow (gpm)	Perm. Flow (gpm)	Flux (gfd)	Perm. Total (gal)	Daily Vol. (gal)	Per. COD	Con. TS	Source	Notes
																ratio
MB2	8/10/2002	1&2	9:00 PM	28:30	105	49	44	7.2	0.710	102	10841	433	1520	1.95	WASH INF	2.89 washdown ratio
MB2	8/10/2002	1&2	9:00 PM	28:30	80	45	39	8.3	0.600	86					FLUSH	
MB2	8/10/2002	1&2	9:15 PM	28:45	72	45	39	8.3	0.850	122					FLUSH	
MB3	8/11/2002	1&2	11:15 AM	0:00	78	51	46	7.3	0.700	101	10857			0.84	INF	This is the first production batch
MB3	8/11/2002	1&2	11:40 AM	0:25	85	50	45	7.3	0.610	88	10880				INF	
MB3	8/11/2002	1&2	12:30 PM	1:15	92	50	45	7.3	0.610	88	10909				INF	
MB3	8/11/2002	1&2	7:15 PM	8:00	110	50	44	7.4	0.656	94	11171	314	12100	2.35	INF	67.7% Volume Reduction
MB3	8/11/2002	1&2	7:15 PM	8:00	110	50	44	7.4	0.656	94	11171				WASH INF	
MB3	8/12/2002	1&2	7:15 AM	20:00	105	50	44	7.4	0.680	98	11651	480	1500	1.82	WASH INF	3.2 washdown ratio
MB3	8/12/2002	1&2	7:30 AM	20:15	80	49	40	8.4	0.650	94					FLUSH	
MB3	8/12/2002	1&2	8:40 AM	20:25	80	49	41	8.3	0.850	122					FLUSH	
MB4	8/12/2002	1&2	9:50 AM	0:00	80	50	46	6.7	0.640	92	11681			1.07	INF	
MB4	8/12/2002	1&2	10:10 AM	20:00	81	50	46	6.8	0.570	82					INF	
MB4	8/12/2002	1&2	11:10 AM	1:10	93	50	45	6.7	0.575	83					INF	
MB4	8/12/2002	1&2	12:10 PM	2:10	98	49	45	7.2	0.585	84					INF	
MB4	8/12/2002	1&2	2:00 PM	4:10	103	49	45	7.3	0.585	84					INF	
MB4	8/12/2002	1&2	10:00 PM	12:10	110	49	45	7.1	0.600	86		446	12240	2.57	INF	75% volume Reduction
MB4	8/12/2002	1&2	10:00 PM	12:10	110	49	45	7.1	0.600	86	12127				WASH INF	
MB4	8/13/2002	1&2	7:45 AM	21:55	103	48	45	7.2	0.620	89	12486				WASH INF	
MB4	8/13/2002	1&2	8:15 AM	22:25	103	48	45	7.2	0.620	89	12506	379	2180	ND	WASH INF	2.53 washdown volume to tank ratio

Table A-12. (continued).

Trial No.[a]	Date	Speedy	Time	Elapsed Time (hh:mm)	Temp (°F)	Feed (psi)	Con (psi)	Feed Flow (gpm)	Perm. Flow (gpm)	Flux (gfd)	Perm. Total (gal)	Daily Vol. (gal)	Per. COD	Con. TS	Source	Notes
MB4	8/13/2002	1&2	8:25 AM	22:35	80	49	42	8.3	0.630	91					FLUSH	
MB4	8/13/2002	1&2	8:40 AM	22:45	76	49	42	8.4	0.820	118					FLUSH	
MB5	8/13/2002	1&2	9:00 AM	0:00	80	50	46	7.0	0.484	70	12526			0.76	INF	
MB5	8/13/2002	1&2	10:30 AM	1:30	91	48	44	6.9	0.484	70					INF	
MB5	8/13/2002	1&2	12:15 PM	1:15	110	48	44	7.0	0.546	79					INF	
MB5	8/13/2002	1&2	3:30 PM	3:14	111	48	44	7.0	0.572	82					INF	
MB5	8/13/2002	1&2	10:00 PM	13:00	111	48	44	7.0	0.592	85	12951	425	11780	2.50	INF	74% Volume reduction
MB5	8/13/2002	1&2	10:00 PM	13:00	111	48	44	7.0	0.593	85					WASH INF	
MB5	8/14/2002	1&2	7:15 AM	22:15	109	48	44	7.0	0.592	85	13281	330	2450	1.93	WASH INF	2.16 washdown ratio
MB5	8/14/2002	1&2	7:20 AM	22:20	73	48	42	7.0	0.614	88					FLUSH	
MB5	8/14/2002	1&2	8:00 AM	23:00	72	49	43	8.0	0.698	101					FLUSH	
MB5	8/14/2002	1&2	9:00 AM	24:00	84	48	43	8.0	0.745	107					CLEAN	CIP, MC4 @ pH 11, 150 deg. F
MB5	8/14/2002	1&2	9:10 AM	24:10	100	48	43	8.9	1.007	145					CLEAN	
MB5	8/14/2002	1&2	9:30 AM	24:30	122	48	42	9.0	1.345	194					CLEAN	
MB5	8/14/2002	1&2	10:15 AM	25:15	140	47	38	9.0	1.800	259					CLEAN	
MB5	8/14/2002	1&2	10:40 AM	25:40	150	47	37	10.0	2.000	288					CLEAN	
MB5	8/14/2002	1&2	10:45 AM	25:45	82	49	44	9.0	1.800	259					FLUSH	Excellent Flux revovery
MB5	8/14/2002	1&2	11:00 AM	26:00	87	49	44	9.0	1.643	237					FLUSH	
MB6	8/14/2002	1&2	11:20 AM	0:00	80	51	48	8.0	0.943	136	13473			0.64	INF	
MB6	8/14/2002	1&2	11:35 AM	0:15	87	50	45	7.0	0.821	118					INF	
MB6	8/14/2002	1&2	12:05 PM	0:45	90	50	45	7.0	0.777	112					INF	
MB6	8/14/2002	1&2	8:00 PM	8:40	90	50	45	7.0	0.697	100					INF	
MB6	8/14/2002	1&2	10:00 PM	11:00	90	50	45	7.0	0.680	98	13928	455	12600	2.48	INF	75.2% VR
MB6	8/14/2002	1&2	10:00 PM	11:00	90	49	45	7.0	0.680	98					WASH INF	
MB6	8/15/2002	1&2	7:30 AM	20:30	105	50	45	7.0	0.707	102					WASH INF	

Table A-12. (continued).

Trial No.[a]	Date	Speedy	Time	Elapsed Time (hh:mm)	Temp (°F)	Feed (psi)	Con (psi)	Feed Flow (gpm)	Perm. Flow (gpm)	Flux (gfd)	Perm. Total (gal)	Daily Vol. (gal)	Per. COD	Con. TS	Source	Notes
MB6	8/15/2002	1&2	8:45 AM	21:45	105	50	45	7.0	0.713	103	14375	447	2100	2.10	WASH INF	2.98 ratio
MB6	8/15/2002	1&2	9:15 AM	22:15	65	49	45	8.0	0.758	109					FLUSH	
MB6	8/15/2002	1&2	9:30 AM	22:30	75	50	45	8.0	0.812	117					FLUSH	
MB7	8/15/2002	1&2	10:00 AM	0:00	80	52	48	8.0	0.548	79	14390			0.61	INF	
MB7	8/15/2002	1&2	10:30 AM	0:30	89	50	46	8.0	0.549	79					INF	
MB7	8/15/2002	1&2	11:30 AM	1:30	95	50	46	7.0	0.563	81					INF	
MB7	8/15/2002	1&2	3:00 PM	5:00	109	50	46	7.0	0.621	89					INF	
MB7	8/15/2002	1&2	5:30 PM	7:30	111	50	46	7.0	0.628	90					INF	
MB7	8/15/2002	1&2	9:00 PM	11:00	112	50	46	7.0	0.635	91	14781	391	12450	2.16	INF	72.3 % vr
MB7	8/15/2002	1&2	9:00 PM	11:00	112	50	46	7.0	0.635	91					WASH INF	
MB7	8/16/2002	1&2	7:00 AM	21:00	108	50	46	7.0	0.645	93					WASH INF	
MB7	8/16/2002	1&2	11:30 AM	25:30	108	50	46	7.0	0.663	95					WASH INF	
MB7	8/16/2002	1&2	12:00 PM	26:00	108	50	46	7.0	0.664	96	15363	582	1240	1.88	WASH INF	3.88 ratio
MB7	8/16/2002	1&2	12:15 PM	26:15	70	50	47	7.0	0.662	95					FLUSH	
MB7	8/16/2002	1&2	12:35 PM	26:35	76	48	42	7.0	0.742	107					FLUSH	
MB8	8/16/2002	1&2	1:30 PM	0:00	80	52	47	7.0	0.477	69	15380			0.67	INF	
MB8	8/16/2002	1&2	2:00 PM	0:30	85	52	46	7.0	0.478	69					INF	
MB8	8/16/2002	1&2	3:00 PM	1:30	98	52	46	7.0	0.504	73					INF	
MB8	8/16/2002	1&2	7:00 PM	5:30	110	52	46	7.0	0.594	86					INF	
MB8	8/16/2002	1&2	11:00 PM	9:00	110	50	46	7.0	0.602	87	15698	318	10350	1.84	INF	76.5% vr
MB8	8/16/2002	1&2	11:00 PM	9:00	110	50	46	7.0	0.602	87					WASH INF	
MB8	8/17/2002	1&2	7:00 AM	17:00	108	50	46	7.0	0.620	89					WASH INF	
MB8	8/17/2002	1&2	9:00 AM	19:00	108	50	46	7.0	0.622	90	16072	374	1720	1.55	WASH INF	2.5 ratio
MB8	8/17/2002	1&2	9:05 AM	19:05	78	49	42	8.0	0.633	91					FLUSH	
MB8	8/17/2002	1&2	9:25 AM	19:25	72	49	42	8.0	0.703	101					FLUSH	
MB9	8/17/2002	1&2	7:30 AM	0:00	80	51	48	7.3	0.448	65	16089			0.67	INF	
MB9	8/17/2002	1&2	10:30 AM	3:00	94	51	48	7.3	0.474	68					INF	
MB9	8/17/2002	1&2	12:00 PM	4:30	100	53	49	7.3	0.526	76					INF	
MB9	8/17/2002	1&2	3:00 PM	7:30	110	53	49	7.3	0.590	85					INF	

Table A-12. (continued).

Trial No.[a]	Date	Speedy	Time	Elapsed Time (hh:mm)	Temp (°F)	Feed (psi)	Con (psi)	Feed Flow (gpm)	Perm. Flow (gpm)	Flux (gfd)	Perm. Total (gal)	Daily Vol. (gal)	Per. COD	Con. TS	Source	Notes
MB9	8/17/2002	1&2	6:00 PM	10:30	110	53	49	7.3	0.620	89					INF	
MB9	8/17/2002	1&2	9:00 PM	13:30	112	53	48	7.3	0.621	89	16480	391	15920	2.55	INF	72.3% vr
MB9	8/17/2002	1&2	9:00 PM	13:30	112	53	49	7.3	0.621	89					WASH INF	
MB9	8/18/2002	1&2	7:00 AM	23:30	108	53	49	7.3	0.605	87					WASH INF	
MB9	8/18/2002	1&2	8:05 AM	24:35	108	53	48	7.3	0.598	86	16887	407	2590	1.96	WASH INF	2.7 ratio
MB9	8/18/2002	1&2	8:15 AM	24:45	100	50	42	0.5	1.205	174					CLEAN	
MB9	8/18/2002	1&2	8:40 AM	25:10	142	51	42	9.0	1.495	215					CLEAN	
MB9	8/18/2002	1&2	8:50 AM	25:20	148	51	42	9.0	1.647	237					CLEAN	
MB9	8/18/2002	1&2	9:00 AM	26:30	150	51	42	9.0	1.693	244					CLEAN	
MB9	8/18/2002	1&2	11:00 AM	28:30	80	53	46	9.0	1.058	152					FLUSH	
MB9	8/18/2002	1&2	11:15 AM	28:45	67	52	43	9.0	1.048	151					FLUSH	
MB10	8/18/2002	1&2	11:30 AM	0:00	80	53	47	7.0	0.621	89	16983			0.71	INF	
MB10	8/18/2002	1&2	12:00 PM	0:30	96	53	48	7.0	0.608	88					INF	
MB10	8/18/2002	1&2	1:00 PM	1:30	99	53	49	7.0	0.600	86					INF	
MB10	8/18/2002	1&2	4:00 PM	3:30	106	53	49	7.0	0.641	92					INF	
MB10	8/18/2002	1&2	7:00 PM	7:30	108	53	49	7.0	0.644	93					INF	
MB10	8/18/2002	1&2	10:00 PM	10:30	108	53	49	7.0	0.623	90			13560	2.35	INF	
MB10	8/19/2002	1&2	10:00 PM	10:30	108	53	49	7.0	0.623	90	17377	394			WASH INF	72.4% vr
MB10	8/19/2002	1&2	7:05 AM	18:35	106	53	49	7.0	0.626	90					WASH INF	
MB10	8/19/2002	1&2	9:05 AM	20:35	106	53	49	7.0	0.635	91					WASH INF	
MB10	8/19/2002	1&2	10:00 AM	22:30	106	53	48	7.0	0.636	92	17826	449	1510	1.72	WASH INF	3.0 ratio
MB10	8/19/2002	1&2	10:05 AM	22:35	80	53	44	8.0	0.659	95					FLUSH	
MB10	8/19/2002	1&2	10:25 AM	22:55	70	53	44	8.0	0.782	113					FLUSH	
MB11	8/19/2002	1&2	11:00 AM	0:00	80	56	49	7.0	0.559	80	17844			0.60	INF	
MB11	8/19/2002	1&2	11:30 AM	0:30	90	53	49	7.0	0.561	81					INF	
MB11	8/19/2002	1&2	12:00 AM	1:00	98	53	49	7.0	0.582	84					INF	
MB11	8/19/2002	1&2	3:00 PM	4:00	108	53	48	7.0	0.583	84					INF	
MB11	8/19/2002	1&2	6:30 PM	7:30	108	53	48	7.0	0.593	85					INF	
MB11	8/19/2002	1&2	10:00 PM	11:00	108	53	48	7.0	0.598	86	18108	264	13800	1.78	INF	63.8% vr

Table A-12. (continued).

Trial No.[a]	Date	Speedy	Time	Elapsed Time (hh:mm)	Temp (°F)	Feed (psi)	Con (psi)	Feed Flow (gpm)	Perm. Flow (gpm)	Flux (gfd)	Perm. Total (gal)	Daily Vol. (gal)	Per. COD	Con. TS	Source	Notes
MB11	8/19/2002	1&2	10:00 PM	11:00	108	53	48	7.0	0.598	86					WASH INF	
MB11	8/20/2002	1&2	7:15 AM	20:15	100	53	48	7.0	0.573	83					WASH INF	
MB11	8/20/2002	1&2	9:45 AM	22:45	100	53	48	7.0	0.574	83	18611	503	2010	1.35	WASH INF	3.35 ratio
MB11	8/20/2002	1&2	10:15 AM	23:15	70	53	46	8.0	0.590	85					CLEAN	
MB11	8/20/2002	1&2	10:30 AM	23:30	110	53	46	8.0	0.286	41					CLEAN	cleaning foamed, causing low flux
MB11	8/20/2002	1&2	10:55 AM	23:55	70	52	46	8.0	0.634	91					FLUSH	
MB11	8/20/2002	1&2	11:05 AM	24:05	70	51	43	8.9	1.009	145					FLUSH	
MB11	8/20/2002	1&2	11:15 AM	24:15	70	51	44	9.0	1.011	146					FLUSH	
MB12	8/21/2002	1&2	9:30 AM	0:00	70	54	50	7.0	0.722	104	18669			0.73	INF	
MB12	8/21/2002	1&2	10:00 AM	0:30	80	53	49	7.0	0.667	96					INF	
MB12	8/21/2002	1&2	11:00 AM	1:30	89	53	49	7.0	0.665	96					INF	
MB12	8/21/2002	1&2	2:30 PM	5:00	104	53	49	7.0	0.657	95					INF	
MB12	8/21/2002	1&2	6:00 PM	8:30	108	53	49	7.0	0.645	93					INF	
MB12	8/21/2002	1&2	9:30 PM	12:00	108	53	49	7.0	0.609	88	19000	331	11800	2.91	INF	68.8% vr
MB12	8/21/2002	1&2	9:30 PM	12:00	108	53	49	7.0	0.609	88					WASH INF	
MB12	8/22/2002	1&2	7:00 AM	21:30	106	53	49	7.0	0.602	87					WASH INF	
MB12	8/22/2002	1&2	8:00 AM	22:30	106	53	48	7.0	0.602	87					WASH INF	
MB12	8/22/2002	1&2	9:00 AM	23:30	106	53	48	7.0	0.603	87					WASH INF	
MB12	8/22/2002	1&2	9:30 AM	24:00	106	53	48	7.0	0.599	86	19599	599	1770	2.27	WASH INF	4.0 ratio
MB12	8/22/2002	1&2	9:35 AM	24:05	80	52	44	8.0	0.599	86					FLUSH	
MB12	8/22/2002	1&2	10:00 AM	24:30	70	52	44	8.0	0.706	102					FLUSH	
MB13	8/22/2002	1&2	11:00 AM	0:00	78	55	50	7.0	0.544	78	19541			0.59	INF	
MB13	8/22/2002	1&2	11:30 AM	0:30	88	53	49	7.0	0.501	72					INF	
MB13	8/22/2002	1&2	12:30 PM	1:30	88	53	49	7.0	0.519	75					INF	
MB13	8/22/2002	1&2	4:00 PM	5:00	108	53	49	7.0	0.543	78					INF	
MB13	8/22/2002	1&2	7:00 PM	8:00	110	53	49	7.0	0.542	78					INF	
MB13	8/22/2002	1&2	11:00 PM	12:00	110	53	49	7.0	0.522	75	19843	302	11970	2.09	INF	66.8% vr

Table A-12. (continued).

Trial No.[a]	Date	Speedy	Time	Elapsed Time (hh:mm)	Temp (°F)	Feed (psi)	Con (psi)	Feed Flow (gpm)	Perm. Flow (gpm)	Flux (gfd)	Perm. Total (gal)	Daily Vol. (gal)	Per. COD	Con. TS	Source	Notes
MB13	8/22/2002	1&2	11:00 PM	12:00	110	53	49	7.0	0.522	75					WASH INF	
MB13	8/23/2002	1&2	7:00 AM	20:00	108	53	49	7.0	0.523	75					WASH INF	
MB13	8/23/2002	1&2	8:30 AM	21:30	108	53	49	7.0	0.524	75					WASH INF	
MB13	8/23/2002	1&2	9:30 AM	22:30	108	53	48	7.0	0.526	76					WASH INF	
MB13	8/23/2002	1&2	11:00 AM	24:00	108	53	49	7.0	0.527	76	20350	507	2080	1.60	WASH INF	3.38 ratio
MB13	8/23/2002	1&2	11:05 AM	24:05	90	52	49	8.0	0.513	74					FLUSH	
MB13	8/23/2002	1&2	11:20 AM	24:20	72	52	44	8.3	0.612	88					FLUSH	
MB13	8/23/2002	1&2	11:45 AM	24:45	72	53	44	8.0	0.386	56					CLEAN	
MB13	8/23/2002	1&2	12:15 PM	25:15	90	53	46	8.9	0.556	80					CLEAN	
MB13	8/23/2002	1&2	1:15 PM	26:15	124	51	45	9.0	0.873	126					CLEAN	
MB13	8/23/2002	1&2	2:00 PM	27:00	142	51	44	9.4	1.164	168					CLEAN	
MB13	8/23/2002	1&2	2:15 PM	27:15	72	51	43	9.3	1.196	172					FLUSH	
MB13	8/23/2002	1&2	2:30 PM	27:30	72	51	44	9.3	1.309	188					FLUSH	
MB14	8/24/2002	1&2	10:15 AM	0:00	74	53	49	8.0	0.865	125	20482			0.61	INF	
MB14	8/24/2002	1&2	10:45 AM	0:30	84	53	49	7.6	0.812	117					INF	
MB14	8/24/2002	1&2	11:45 AM	1:30	90	53	49	7.0	0.785	113					INF	
MB14	8/24/2002	1&2	4:00 PM	5:45	102	53	49	7.5	0.700	101					INF	
MB14	8/24/2002	1&2	7:00 PM	8:45	104	53	48	7.2	0.662	95					INF	76.7% vr
MB14	8/24/2002	1&2	10:00 PM	11:45	104	53	48	7.2	0.638	92	20975	493	12310	2.57	INF	
MB14	8/25/2002	1&2	10:00 PM	11:45	100	53	48	7.0	0.638	92					WASH INF	
MB14	8/25/2002	1&2	7:00 AM	20:45	100	52	48	7.0	0.637	92					WASH INF	
MB14	8/25/2002	1&2	8:00 AM	21:45	100	52	48	7.0	0.640	92					WASH INF	
MB14	8/25/2002	1&2	9:00 AM	22:45	100	52	48	7.0	0.644	93					WASH INF	
MB14	8/25/2002	1&2	9:45 AM	23:30	100	52	48	7.0	0.647	93	21424	449	1730	2.22	WASH INF	3.0 ratio
MB14	8/25/2002	1&2	9:47 AM	23:32	80	50	44	8.0	0.579	83					FLUSH	
MB14	8/25/2002	1&2	10:05 AM	23:50	72	50	43	8.9	0.802	115					FLUSH	
MB15	8/25/2002	1&2	10:05 AM	0:00	72	52	49	8.0	0.593	85	21438			0.60	INF	
MB15	8/25/2002	1&2	10:35 AM	0:30	72	52	49	7.3	0.560	81					INF	
MB15	8/25/2002	1&2	11:30 AM	0:55	84	52	49	7.0	0.581	84					INF	

Table A-12. (continued).

Trial No.[a]	Date	Speedy	Time	Elapsed Time (hh:mm)	Temp (°F)	Feed (psi)	Con (psi)	Feed Flow (gpm)	Perm. Flow (gpm)	Flux (gfd)	Perm. Total (gal)	Daily Vol. (gal)	Per. COD	Con. TS	Source	Notes
MB15	8/25/2002	1&2	3:00 PM	5:00	90	52	48	7.0	0.605	87					INF	
MB15	8/25/2002	1&2	6:00 PM	8:00	104	52	48	7.0	0.602	87					INF	
MB15	8/25/2002	1&2	10:00 PM	12:00	108	52	48	7.0	0.589	85	21860	422	12320	2.19	INF	73.8 %vr
MB15	8/25/2002	1&2	10:00 PM	12:00	108	52	48	7.0	0.589	85					WASH INF	
MB15	8/26/2002	1&2	7:00 AM	21:00	102	52	48	7.0	0.568	82					WASH INF	
MB15	8/26/2002	1&2	8:00 AM	22:00	102	52	48	7.0	0.569	82					WASH INF	
MB15	8/25/2002	1&2	9:00 AM	23:00	102	52	48	7.0	0.572	82					WASH INF	
MB15	8/26/2002	1&2	10:00 AM	24:00	102	52	48	7.0	0.573	83	22275	415	1700	1.98	WASH INF	2.77 ratio
MB15	8/26/2002	1&2	10:05 AM	24:00	82	50	44	8.0	0.511	74					FLUSH	
MB15	8/26/2002	1&2	10:25 AM	24:20	70	50	43	8.0	0.710	102					FLUSH	
MB16	8/27/2002	1&2	8:50 AM	0:00	68	53	49	7.2	0.530	76	22291			0.60	INF	
MB16	8/27/2002	1&2	9:30 AM	0:40	80	52	48	7.0	0.510	73					INF	
MB16	8/27/2002	1&2	10:30 AM	1:40	90	52	49	7.0	0.533	77					INF	
MB16	8/27/2002	1&2	2:00 PM	5:10	104	52	48	7.0	0.584	84					INF	
MB16	8/27/2002	1&2	5:00 PM	8:10	108	52	48	7.0	0.590	85					INF	
MB16	8/27/2002	1&2	8:50 PM	12:00	106	52	49	7.3	0.561	81	22698	407	13360	2.12	INF	73.0 % vr
MB16	8/27/2002	1&2	8:50 PM	12:00	106	52	49	7.0	0.561	81					WASH INF	
MB16	8/28/2002	1&2	7:00 AM	22:10	100	52	48	7.0	0.536	77					WASH INF	
MB16	8/28/2002	1&2	8:00 AM	23:10	100	52	48	7.0	0.550	79					WASH INF	
MB16	8/28/2002	1&2	8:50 AM	24:00	100	52	48	7.0	0.534	77	23087	389	1975	1.86	WASH INF	2.6 ratio
MB16	8/28/2002	1&2	8:55 AM	24:05	82	51	44	8.0	0.518	75					FLUSH	
MB16	8/28/2002	1&2	9:15 AM	24:25	70	50	44	8.3	0.673	97					FLUSH	
MB16	8/28/2002	1&2	10:00 AM	25:10	68	56	43	8.4	0.479	69					CLEAN	
MB16	8/28/2002	1&2	11:00 AM	26:10	118	54	45	9.0	0.922	133					CLEAN	
MB16	8/28/2002	1&2	11:55 AM	27:05	150	51	43	7.8	1.369	197					CLEAN	
MB16	8/28/2002	1&2	12:20 PM	27:30	82	52	44	9.0	1.082	156					FLUSH	
MB16	8/28/2002	1&2	12:40 PM	27:50	71	51	43	9.0	1.168	168					FLUSH	
MB17	9/3/2002	1&2	11:45 AM	0:00	78	53	49	7.8	0.855	123				0.85	INF	
MB17	9/3/2002	1&2	1:00 PM	1:15	90	53	48	7.7	0.818	118					INF	

Table A-12. (continued).

Trial No.[a]	Date	Speedy	Time	Elapsed Time (hh:mm)	Temp (°F)	Feed (psi)	Con (psi)	Feed Flow (gpm)	Perm. Flow (gpm)	Flux (gfd)	Perm. Total (gal)	Daily Vol. (gal)	Per. COD	Con. TS	Source	Notes
MB17	9/3/2002	1&2	4:30 PM	4:45	102	52	47	7.5	0.786	113					INF	
MB17	9/3/2002	1&2	12:30 AM	12:45	104	52	48	7.5	0.692	100			8320	3.25	INF	
MB17	9/3/2002	1&2	12:30 AM	12:45	104	52	48	7.5	0.692	100					WASH INF	
MB17	9/4/2002	1&2	8:30 AM	20:45	98	52	48	7.2	0.682	98					WASH INF	
MB17	9/4/2002	1&2	9:45 AM	21:30	99	52	48	7.2	0.680	98			1512	2.72	WASH INF	
MB17	9/4/2002	1&2	9:45 AM	21:30	84	51	44	8.4	0.559	80					FLUSH	
MB17	9/4/2002	1&2	10:00 AM	21:45	84	51	45	8.4	0.760	109					FLUSH	
MB18	9/4/2002	1&2	10:00 AM	0:00	76	52	44	7.3	0.619	89	24195			1.23	INF	
MB18	9/4/2002	1&2	10:45 AM	0:45	86	52	48	7.4	0.600	86					INF	
MB18	9/4/2002	1&2	1:00 PM	3:00	97	52	48	7.5	0.664	96					INF	
MB18	9/4/2002	1&2	11:00 PM	13:00	105	52	48	7.3	0.621	89	24700	505	18840	4.18	INF	77% vr
MB18	9/4/2002	1&2	11:00 PM	13:00	105	52	48	7.3	0.611	88					WASH INF	
MB18	9/5/2002	1&2	7:45 AM	21:45	100	52	48	7.3	0.611	88					WASH INF	
MB18	9/5/2002	1&2	9:00 AM	23:00	100	50	48	7.3	0.640	92	25070	370	3100	3.30	WASH INF	2.47 ratio
MB18	9/5/2002	1&2	9:00 AM	23:00	74	50	43	8.5	0.620	89					FLUSH	
MB18	9/5/2002	1&2	9:15 AM	23:15	76	50	43	8.5	0.752	108					FLUSH	
MB19	9/5/2002	1&2	9:15 AM	0:00	74	52	49	7.3	0.550	79	25084			0.84	INF	
MB19	9/5/2002	1&2	9:30 AM	0:15	78	52	49	7.3	0.549	79					INF	
MB19	9/5/2002	1&2	12:15 PM	3:00	95	52	48	7.3	0.638	92					INF	
MB19	9/5/2002	1&2	9:00 PM	11:45	104	52	48	7.3	0.638	92	25531	447	15750	2.92	INF	74.9% vr
MB19	9/5/2002	1&2	9:00 PM	11:45	104	52	48	7.3	0.638	92					WASH INF	
MB19	9/6/2002	1&2	7:45 AM	22:30	98	50	48	7.5	0.616	89	25936	405	2100	2.40	WASH INF	2.7 ratio
MB19	9/6/2002	1&2	7:50 AM	22:35	72	50	43	8.5	0.490	71					FLUSH	
MB19	9/6/2002	1&2	8:10 AM	22:55	70	50	43	8.7	0.730	105					FLUSH	
MB20	9/7/2002	1&2	8:15 AM	0:00	70	52	48	7.1	0.525	76	25955			0.88	INF	
MB20	9/7/2002	1&2	9:15 AM	1:00	82	52	48	7.2	0.544	78					INF	
MB20	9/7/2002	1&2	2:45 PM	6:30	102	52	48	7.7	0.638	92					INF	
MB20	9/7/2002	1&2	9:00 PM	12:45	105	52	48	7.3	0.630	91	26434	479	15500	3.32	INF	76.2% vr
MB20	9/7/2002	1&2	9:00 PM	12:45	105	52	48	7.4	0.630	91					WASH INF	

Table A-12. (continued).

Trial No.[a]	Date	Speedy	Time	Elapsed Time (hh:mm)	Temp (°F)	Feed (psi)	Con (psi)	Feed Flow (gpm)	Perm. Flow (gpm)	Flux (gfd)	Perm. Total (gal)	Daily Vol. (gal)	Per. COD	Con. TS	Source	Notes
MB20	9/8/2002	1&2	8:00 AM	23:45	100	52	48	7.3	0.600	86					WASH INF	
MB20	9/8/2002	1&2	8:30 AM	24:15	100	51	48	7.3	0.606	87	26853	419	2600	2.90	WASH INF	2.80 ratio
MB20	9/8/2002	1&2	8:30 AM	24:15	76	51	43	8.5	0.565	81					FLUSH	
MB20	9/8/2002	1&2	8:50 AM	24:35	78	51	43	8.6	0.695	100					FLUSH	
MB20	9/8/2002	1&2	8:55 AM	24:40	70	51	43	8.8	0.550	79					CLEAN	
MB20	9/8/2002	1&2	9:20 AM	25:05	93	51	44	9.1	0.950	137					CLEAN	
MB20	9/8/2002	1&2	9:45 AM	25:20	137	51	43	9.8	1.650	238					CLEAN	
MB20	9/8/2002	1&2	9:50 AM	25:25	78	50	43	9.3	1.050	151					FLUSH	
MB21	9/9/2002	1&2	11:30 AM	0:00	75	52	44	9.0	0.820	118	26993			0.84	INF	
MB21	9/9/2002	1&2	11:35 AM	0:05	80	52	49	8.0	0.843	121					INF	
MB21	9/9/2002	1&2	9:30 PM	10:00	108	52	49	7.8	0.767	110	27505	512	13500	2.97	INF	77.3% vr
MB21	9/9/2002	1&2	9:30 PM	10:00	108	52	49	7.8	0.767	110					WASH INF	
MB21	9/10/2002	1&2	9:30 AM	22:00	100	52	49	7.8	0.741	107	28037	532	1230	2.56	WASH INF	3.5 ratio
MB21	9/10/2002	1&2	9:45 AM	22:15	80	50	44	8.6	0.650	94					FLUSH	
MB21	9/10/2002	1&2	10:00 AM	22:30	70	50	4	8.8	0.755	109					FLUSH	
MB22	9/10/2002	1&2	9:30 AM	0:00	77	51	47	7.2	0.723	104	28060			0.81	INF	
MB22	9/10/2002	1&2	9:45 AM	0:15	80	50	46	7.2	0.734	106					INF	
MB22	9/10/2002	1&2	3:00 PM	7:30	110	50	45	7.2	0.810	117					INF	
MB22	9/10/2002	1&2	9:00 PM	11:30	109	50	45	7.4	0.725	104	28604	544	15200	3.63	INF	78.4%vr
MB22	9/10/2002	1&2	9:00 PM	11:30	109	50	45	7.4	0.725	104					WASH INF	
MB22	9/11/2002	1&2	8:00 AM	22:30	100	50	45	7.6	0.694	100					WASH INF	LOST 40 GALLONS
MB22	9/11/2002	1&2	8:30 AM	23:00	100	50	45	7.7	0.697	100	29077	473	1640	3.18	WASH INF	3.15 ratio
MB22	9/11/2002	1&2	8:30 AM	23:00	80	49	42	8.5	0.650	94					FLUSH	
MB22	9/11/2002	1&2	8:45 AM	23:15	80	49	42	8.7	0.820	118					FLUSH	
MB23	9/11/2002	1&2	10:15 AM	0:00	70	51	46	7.4	0.682	98	29086			0.57	INF	
MB23	9/11/2002	1&2	9:00 PM	10:45	100	50	46	7.4	0.676	97	29517	431	12700	2.18	INF	74.2% vr
MB23	9/11/2002	1&2	9:00 PM	10:45	100	50	46	7.4	0.676	97					WASH INF	
MB23	9/12/2002	1&2	7:00 AM	20:45	92	50	46	7.7	0.684	98	29960	443	1750	1.77	WASH INF	2.95 ratio

Table A-12. (continued).

Trial No.[a]	Date	Speedy	Time	Elapsed Time (hh:mm)	Temp (°F)	Feed (psi)	Con (psi)	Feed Flow (gpm)	Perm. Flow (gpm)	Flux (gfd)	Perm. Total (gal)	Daily Vol. (gal)	Per. COD	Con. TS	Source	Notes
MB23	9/12/2002	1&2	7:15 AM	23:00	75	50	42	8.8	0.560	81					FLUSH	
MB23	9/12/2002	1&2	7:30 AM	23:15	75	50	42	8.7	0.780	112					FLUSH	
MB24	9/13/2002	1&2	1:30 PM	0:00	70	50	47	7.3	0.686	99	29966			ND	INF	
MB24	9/13/2002	1&2	3:00 PM	1:30	84	50	46	7.6	0.671	97					INF	
MB24	9/13/2002	1&2	7:15 PM	5:45	100	49	45	7.6	0.707	102					INF	
MB24	9/13/2002	1&2	7:45 PM	6:15	100	49	45	7.2	0.709	102					INF	
MB24	9/14/2002	1&2	7:35 AM	18:05	100	49	46	7.3	0.617	89					INF	
MB24	9/14/2002	1&2	8:30 AM	19:00	100	49	46	7.3	0.619	89	30726	760	13400	3.55	INF	83.5% vr
MB24	9/14/2002	1&2	8:30 AM	19:00	100	49	46	7.3	0.619	89					WASH INF	
MB24	9/14/2002	1&2	10:00 AM	20:30	100	49	45	7.3	0.610	88					WASH INF	
MB24	9/14/2002	1&2	4:00 PM	26:30	106	50	46	7.4	0.654	94					WASH INF	
MB24	9/14/2002	1&2	8:30 PM	24:45	104	49	46	7.4	0.661	95	31176	450	1700	3.67	WASH INF	3.00 ratio
MB24	9/14/2002	1&2	8:30 PM	24:45	80	49	42	8.9	0.647	93					FLUSH	
MB24	9/14/2002	1&2	8:45 PM	25:00	70	49	42	8.4	0.790	114					FLUSH	
MB24	9/15/2002	1&2	8:00 AM	36:45	100	50	43	8.3	0.752	108					CLEAN	
MB24	9/15/2002	1&2	8:30 AM	37:15	100	49	42	8.8	1.039	150					CLEAN	
MB24	9/15/2002	1&2	9:00 AM	37:45	120	49	42	9.0	1.161	167					CLEAN	
MB24	9/15/2002	1&2	9:30 AM	38:15	134	49	40	9.2	1.260	181					CLEAN	
MB24	9/15/2002	1&2	10:15 AM	39:00	150	48	40	9.5	1.417	204					CLEAN	
MB24	9/15/2002	1&2	10:40 AM	39:20	74	50	42	8.9	0.961	138					FLUSH	
MB24	9/15/2002	1&2	11:00 AM	39:40	74	49	40	9.9	1.196	172					FLUSH	
MB25	9/16/2002	1&2	10:00 AM	0:00	65	50	48	7.2	0.722	104	31379			0.77	INF	
MB25	9/16/2002	1&2	10:35 AM	0:30	84	48	45	7.2	0.735	106					INF	
MB25	9/16/2002	1&2	11:35 AM	1:30	88	50	46	7.2	0.727	105					INF	
MB25	9/16/2002	1&2	3:00 PM	5:00	98	49	46	7.2	0.763	110					INF	
MB25	9/16/2002	1&2	7:00 PM	9:00	100	49	45	7.1	0.730	105					INF	
MB25	9/16/2002	1&2	10:00 PM	12:00	99	49	46	7.2	0.696	100	31899	520	14600	2.43	INF	77.6% vr
MB25	9/16/2002	1&2	10:00 PM	12:00	96	49	46	7.2	0.696	100					WASH INF	
MB25	9/16/2002	1&2	7:00 AM	21:00	96	49	46	7.3	0.705	102					WASH INF	

Table A-12. (continued).

Trial No.[a]	Date	Speedy	Time	Elapsed Time (hh:mm)	Temp (°F)	Feed (psi)	Con (psi)	Feed Flow (gpm)	Perm. Flow (gpm)	Flux (gfd)	Perm. Total (gal)	Daily Vol. (gal)	Per. COD	Con. TS	Source	Notes
MB25	9/16/2002	1&2	8:00 AM	22:00	96	50	46	7.2	0.708	102					WASH INF	
MB25	9/16/2002	1&2	9:00 AM	23:00	96	50	46	7.2	0.710	102					WASH INF	
MB25	9/16/2002	1&2	9:30 AM	23:30	96	49	46	7.4	0.715	103	32391	492	1530	2.87	WASH INF	3.28 ratio
MB25	9/16/2002	1&2	9:45 AM	23:45	74	49	44	8.2	0.644	93					FLUSH	
MB25	9/16/2002	1&2	10:00 AM	24:00	70	49	42	8.6	0.874	126					FLUSH	
MB26	9/17/2002	1&2	10:00 AM	0:00	70	50	46	7.2	0.630	91	32409			0.98	INF	
MB26	9/17/2002	1&2	10:30 AM	0:30	78	50	46	7.3	0.628	90					INF	
MB26	9/17/2002	1&2	11:30 AM	1:30	88	50	46	7.4	0.678	98					INF	
MB26	9/17/2002	1&2	4:45 PM	6:45	102	49	46	7.6	0.725	104					INF	
MB26	9/17/2002	1&2	7:00 PM	9:00	102	49	45	7.3	0.713	103					INF	
MB26	9/17/2002	1&2	9:30 PM	11:30	102	49	45	7.4	0.686	99	32893	484	13800	2.91	INF	76.3% vr
MB26	9/18/2002	1&2	9:30 PM	11:30	102	49	46	7.6	0.686	99					WASH INF	
MB26	9/18/2002	1&2	7:30 AM	21:30	98	49	46	7.5	0.688	99					WASH INF	
MB26	9/18/2002	1&2	8:30 AM	22:30	98	49	46	7.6	0.689	99					WASH INF	
MB26	9/18/2002	1&2	9:30 AM	23:30	98	49	45	7.5	0.691	100	33389	496	1400	2.38	WASH INF	3.3 ratio
MB26	9/18/2002	1&2	9:35 AM	23:35	78	49	42	8.5	0.629	91					FLUSH	
MB26	9/18/2002	1&2	10:00 AM	24:00	70	49	42	8.6	0.820	118					FLUSH	
MB27	9/20/2002	1&2	10:00 AM	0:00	76	50	46	736.0	0.689	99	33411			0.83	INF	
MB27	9/20/2002	1&2	10:45 AM	0:45	88	50	46	7.5	0.650	94					INF	
MB27	9/20/2002	1&2	11:45 AM	1:45	92	50	46	7.6	0.679	98					INF	
MB27	9/20/2002	1&2	3:00 PM	5:00	106	50	45	7.2	0.743	107					INF	
MB27	9/20/2002	1&2	7:00 PM	9:00	108	49	45	7.4	0.740	107					INF	
MB27	9/20/2002	1&2	10:15 PM	12:15	108	49	45	7.3	0.700	101	33930	519	21700	3.19	INF	77.6% vr
MB27	9/20/2002	1&2	10:15 PM	12:15	108	49	46	7.3	0.700	101					WASH INF	
MB27	9/21/2002	1&2	7:15 AM	21:15	100	50	466	7.3	0.668	96					WASH INF	
MB27	9/21/2002	1&2	8:15 AM	22:15	100	50	46	7.3	0.644	93					WASH INF	2.5 ratio
MB27	9/21/2002	1&2	9:00 AM	23:00	100	49	46	7.3	0.665	96					WASH INF	

Table A-12. (continued).

Trial No.[a]	Date	Speedy	Time	Elapsed Time (hh:mm)	Temp (°F)	Feed (psi)	Con (psi)	Feed Flow (gpm)	Perm. Flow (gpm)	Flux (gfd)	Perm. Total (gal)	Daily Vol. (gal)	Per. COD	Con. TS	Source	Notes
MB27	9/21/2002	1&2	10:00 AM	24:00	100	49	46	7.3	0.665	96	34305	375	2150	2.75	WASH INF	Cleaning was done because of extra time before starting the next batch, not because of low flux
MB27	9/21/2002	1&2	10:00 AM	24:00	88	49	42	8.2	0.662	95					FLUSH	
MB27	9/21/2002	1&2	10:15 AM	24:15	70	49	42	8.5	0.782	113					FLUSH	
MB27	9/21/2002	1&2	10:25 AM	24:25	70	50	44	8.3	0.652	94					CLEAN	MC4, PH12
MB27	9/21/2002	1&2	11:15 AM	25:15	120	48	42	8.8	0.919	132					CLEAN	
MB27	9/21/2002	1&2	11:55 AM	25:55	144	47	41	9.0	1.052	151					CLEAN	
MB27	9/21/2002	1&2	12:10 PM	26:10	150	47	40	9.3	1.104	159					CLEAN	
MB27	9/21/2002	1&2	12:25 PM	26:25	72	45	44	8.5	0.752	108					FLUSH	
MB27	9/21/2002	1&2	12:45 PM	26:45	70	48	42	8.9	1.110	160					FLUSH	
MB28	9/22/2002	1&2	9:15 AM	0:00	70	50	46	7.4	0.750	108	34531			0.94	INF	
MB28	9/22/2002	1&2	9:45 AM	0:30	80	50	46	7.3	0.693	100					INF	
MB28	9/22/2002	1&2	11:30 AM	2:15	94	49	45	7.2	0.702	101					INF	
MB28	9/22/2002	1&2	5:00 PM	7:45	100	49	45	6.9	0.634	91					INF	
MB28	9/22/2002	1&2	8:15 PM	11:00	100	49	45	6.9	0.594	86	35001	470	14700	3.07	INF	75.8% vr
MB28	9/22/2002	1&2	9:15 PM	12:00	100	49	45	7.0	0.580	84					WASH INF	
MB28	9/23/2002	1&2	9:15 PM	12:00	100	49	45	6.8	0.613	88					WASH INF	
MB28	9/23/2002	1&2	7:15 AM	22:00	100	49	45	7.1	0.619	89					WASH INF	2.85 ratio
MB28	9/23/2002	1&2	8:15 AM	23:00	100	49	45	6.8	0.631	91	35428	427	2000	2.61	WASH INF	
MB28	9/23/2002	1&2	9:15 AM	24:00	70	49	42	8.7	0.630	91					FLUSH	
MB28	9/23/2002	1&2	9:20 AM	24:05	70	49	42	8.8	0.804	116					FLUSH	
MB29	9/23/2002	1&2	12:30 PM	0:00	68	50	46	7.3	0.606	87	35450			0.81	INF	
MB29	9/23/2002	1&2	1:15 PM	0:45	80	50	46	7.3	0.607	87					INF	
MB29	9/23/2002	1&2	2:15 PM	1:45	84	50	46	7.3	0.608	88					INF	
MB29	9/23/2002	1&2	3:00 PM	2:30	90	50	46	7.5	0.633	91					INF	
MB29	9/23/2002	1&2	7:00 PM	6:30	98	50	46	7.8	0.661	95					INF	

Table A-12. (continued).

Trial No.[a]	Date	Speedy	Time	Elapsed Time (hh:mm)	Temp (°F)	Feed (psi)	Con (psi)	Feed Flow (gpm)	Perm. Flow (gpm)	Flux (gfd)	Perm. Total (gal)	Daily Vol. (gal)	Per. COD	Con. TS	Source	Notes
MB29	9/23/2002	1&2	11:15 PM	10:45	92	50	46	7.8	0.619	89	35849	399	14800	2.89	INF	72.7% vr
MB29	9/24/2002	1&2	11:15 PM	10:45	90	49	46	7.8	0.619	89					WASH INF	
MB29	9/24/2002	1&2	7:45 AM	19:15	90	49	45	7.9	0.638	92					WASH INF	
MB29	9/24/2002	1&2	8:45 AM	20:15	90	49	46	7.8	0.647	93					WASH INF	
MB29	9/24/2002	1&2	10:30 AM	22:00	90	49	45	7.7	0.651	94	36265	416	1970	2.13	WASH INF	2.77 ratio
MB29	9/24/2002	1&2	10:35 AM	22:05	80	49	42	8.8	0.556	80					FLUSH	
MB29	9/24/2002	1&2	10:50 AM	22:20	70	48	42	9.2	0.691	100					FLUSH	
MB29	9/24/2002	1&2	10:55 AM	22:25	68	49	44	8.8	0.615	89					CLEAN	
MB29	9/24/2002	1&2	11:30 AM	23:00	98	49	42	9.1	0.854	123					CLEAN	
MB29	9/24/2002	1&2	12:30 PM	24:00	132	49	42	8.8	1.020	147					CLEAN	
MB29	9/24/2002	1&2	12:45 PM	24:15	140	49	41	8.9	1.068	154					CLEAN	
MB29	9/24/2002	1&2	1:05 PM	24:35	70	49	43	8.5	0.787	113					FLUSH	
MB29	9/24/2002	1&2	1:25 PM	24:55	70	49	42	8.5	1.010	145					FLUSH	Test Complete

a. “MB” designates tests performed in this project. The MB was omitted in the body of the report. So “Trial x” in Table 7 is “Trial MBx” in this table.